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ORIGIN OF THE DARWIN SILVER–LEAD DEPOSITS.

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ABSTRACT.

In recent years the number of deposits that are classed as contact metamorphic has become less and less. Many deposits that have been withdrawn from the contact group are now assigned to the pyrometasomatic class.

From early work in the district, Knopf has drawn upon the Darwin deposits to represent the pyrometasomatic type for lead. In the following description of the Darwin deposits, it will be shown that they should be removed even further from the contact group. They should be classed as mesothermal or even, following Graton, leptothermal.

In practically all so-called "contact" deposits the lead minerals can be recognized as late. Hence, it can be concluded that lead minerals are stable only at diminished or intermediate temperatures and pressures. In all probability, therefore, pyrometasomatic lead deposits do not exist.

At Darwin a large stock elongated in a north-south direction has been intruded into limestones of Pennsylvanian age. Around the stock an aureole of silicated rock has developed, which varies in thickness from a few tens to nearly two thousand feet. The original stratification is retained despite silication. Field relations and evidence supported by petrographic and chemical investigations indicate that metasomatism played the dominant rôle in the silication process. Considerable silica and other materials were introduced into the limestones by the magmatic emanations.

The deposition of the ore bodies took place distinctly later than that of the silicate aureole. A period of tectonic fracturing, in which most of the fissures of the district were developed, intervened between the early silication and the later metallization. Three structures, igneous contacts, bedding planes, and fractures controlled the location of the deposits. Genetically all three structural types are the same.

REGIONAL SETTING.

THE Darwin district is located within the desert Basin and Range province of eastern California about 20 miles east of Owens Lake

(Fig. 1). Darwin is 230 miles from Los Angeles and 24 miles from Keeler, the branch terminal of the Southern Pacific railroad.

The Darwin Hills, in which the deposits occur, lie near the center

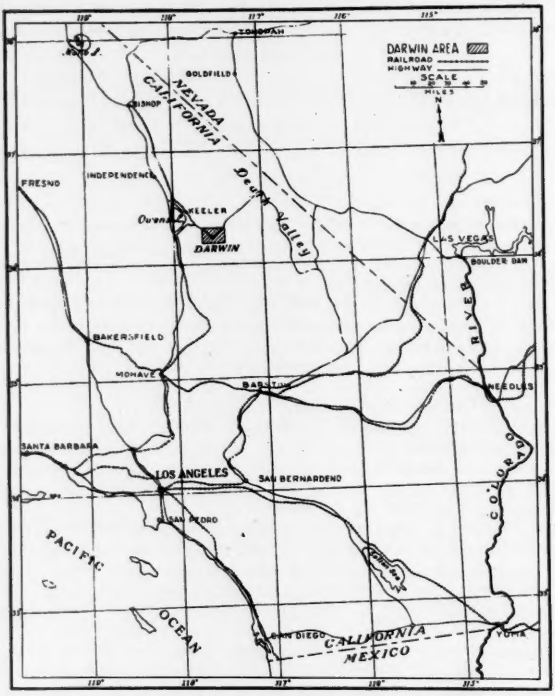


FIG. 1. Location map of the Darwin district.

of a large arched mountain block some thirty miles wide trending in common with other ranges of this region in a north-northwesterly direction. Commonly this large block is considered as three smaller and separate physiographic units, namely, the Inyo Range, Coso Range, and Argus Range (Fig. 2). The Darwin region, however, is a separate geomorphic unit or central plateau above which these adjacent ranges have been elevated by faults.

The general character of the old-land surface which existed prior to the basin and range faulting of Quaternary time is still well preserved on the Darwin Plateau.

The Darwin Hills rise only slightly above the general level of the plateau and trend in a northwesterly direction. The hills proper are six miles in length and rise 500 to 1000 feet above the broad Darwin Wash that borders the hills on the west, south, and east. The town of Darwin is located at an altitude of 4750 feet on the west side of the hills.

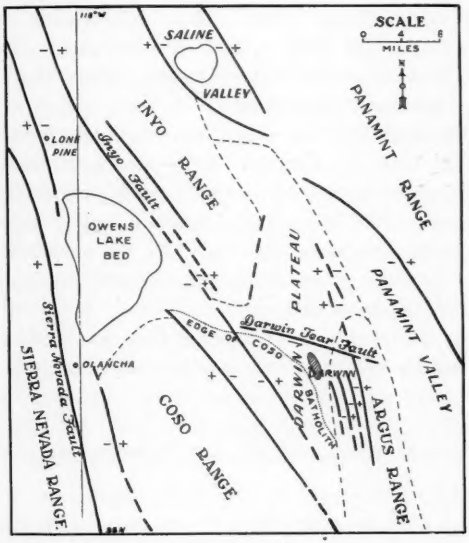


FIG. 2. Major geomorphic and structural features of the Darwin region.

Two contrasting rock types underlie the Darwin Plateau (Fig. 2). The southwestern portion, generally south and west of the road from Darwin to Keeler, is underlain by granodioritic of the Coso batholith, which is closely comparable in texture and composition to the intermediate rocks of the Sierra Nevada batholiths. Occasional patches of older rocks are present as, for

example, on Centennial Flats where large deposits of iron ore occur in a remnant of schist and marble. Commonly the granodiorite of this region is cut by basic dikes, persistent for considerable distances.

The northeasterly part of the plateau is underlain chiefly by folded upper Paleozoic rocks. Knopf [1] has described these rocks in the south end of the Inyo Range where they form folds of Mesozoic age. In the Inyo Range southeast of Keeler these folds are covered by extensive lava sheets, but they emerge again along the strike to the southeast on the Darwin Plateau. Here, they are partially cut off and offset in their distribution around the Coso batholith. The same system of folds passes through the Darwin Hills and thence southeastward, where they are step-faulted up, into the Argus Range.

Here and there the Paleozoic rocks are pierced by small intrusives that may be offshoots from the Coso batholith. In the Darwin region these are exemplified by the quartz diorite stock of the Darwin Hills, the small granitic intrusion near the Lee mine, the gabbroic stock at Darwin Falls, the monzonitic plug at the north end of the Argus Range, and several smaller intrusives southward in the same range.

Northeast of Darwin the truncated Paleozoic beds are extensively capped by basaltic flows, which form a large part of the plateau surface.

GENERAL GEOLOGY OF THE DARWIN HILLS.

Sedimentary Rocks.—A series of Pennsylvanian strata consisting largely of pure and impure limestones intercalated with some quartzite and shale constitute the oldest rocks of the hills. Fossil corals, crinoids, fusulinæ, bryozoa, and occasional ammonites occur in these beds. The state of preservation of the fossils is generally rather poor and exact determinations are therefore difficult. On the basis of determinations made by George H. Girty, Knopf [2] called the formation Pennsylvanian. The

[1] Knopf, A.: U. S. Geol. Surv. Prof. Paper 110, pp. 37–48, 1918.

[2] Knopf, A.: Darwin silver-lead mining district. U. S. Geol. Surv. Bull. 580A, p. 5, 1913.

strata dip westerly across most of the width of the hills and therefore, excluding complete overturning for which there is no evidence, the younger beds crop out on the west flanks of the hills.

The lower strata east of the stock and on the east side of the hills are generally drab and uniform gray or brown in color with few distinct horizons or marker beds. The younger strata, on the other hand, which crop out on the western slopes of the Darwin Hills consist of and are marked by prominent, contrasting light and dark colored limestone members.

The blue-gray limestones which makes up so much of the Pennsylvanian rocks throughout the hills is commonly spotted in appearance due to differential coloring and solubility of fusulinæ and crinoidal remains. A similar spotted appearance is due also to small lenses and nodules of chert in the limestone. Much of the spottedness, however, is clearly due to cemented limestone fragments of depositional origin.

A section across the southern end of the hills shows an inclined series dipping 40–60° west. The thickness of this section, although neither the top nor the bottom of the series is exposed, approximates 5000 feet.

In connection with studies of the silicate rock a chemical analysis of a sample of typical blue-gray limestone was made which showed a content in $CaCO_3$ considerably higher than the average for limestones of Carboniferous age. The table below shows the comparison of the Darwin limestone with Twenhofel's analyses [3] of Carboniferous and Cretaceous limestones.

Limestones	Ratio $CaCO_3 : MgCO_3$	Ratio Ca : Mg
Carboniferous	8.8 : 1	12.4 : 1
Darwin	22.8 : 1	31.5 : 1
Cretaceous	40.2 : 1	56.3 : 1

Igneous Rocks.—The principal igneous rock is the quartz diorite of the Darwin stock which occupies the central portion of the hills. All metallization is associated with this stock. The drab brown color of the weathered quartz diorite causes it to

[3] Twenhofel, W. H.: Treatise on Sedimentation, 1925.

stand out nearly everywhere in strong contrast to the surrounding white silicate aureole. The greater ease with which the stock weathers has caused it to form a lower interior belt of subdued topography surrounded by boldly outcropping stratified rocks.

The stock as a whole displays considerable heterogeneity of composition, but for the most part these variations are only phases of the one intrusive. In nearly all of its phases the rock is medium grained and non-porphyritic. The average or normal phase, here termed the Darwin quartz diorite, is typically a white or light grayish-green rock. The intrusive ranges in composition from quartz monzonite to gabbro. Nearly all of the phases except the most basic ones are oversaturated. In the quartz diorite or even the granodiorite the euhedralism of the plagioclase is the striking textural feature seen under the microscope. Ferromagnesian minerals are ordinarily not abundant, the most common being biotite. Hornblende and augite are only sparingly present in the normal phase, but where the ferromagnesian content is high as in the basic phases the mineral is most commonly augite.

The more basic phases of the intrusive occur in the north and south ends of the long narrow stock. The change towards basicity is gradual yet very irregular and although the ends are more basic they also display more heterogeneity.

There is no evidence that the stock differentiated in place. Contaminating reactions with the country rock do not appear to have affected the composition except locally. No basic border related to early chilling phenomena exists. Instead, the phases appear to be due to original variations in the intruded material. Perhaps the first intruded material was basic and later surges, intermediate in composition, pushed all of the basic material outward and towards the ends. The stock grew centrally with more acidic material continuing to concentrate there.

In places the border portions of the intrusive and the nearby contact aureole contain many dikes. Some of these are direct offshoots of the stock and cut only the country rock. Others are later and cut the intrusive also. These dikes are all more acidic than the intrusive. In some places, offshoots from the intrusive

where traced outward become increasingly acidic, changing sometimes to alaskitic or syenitic dikes. Syenite dikes are common in the contact aureole between the Defiance mine and the Thompson mine. They are coarse grained and composed almost entirely of orthoclase with rarely a little epidote or diopside.

Whereas these and other dikes may have originated as magmatic dikes, the evidence suggests in some cases an origin by metasomatic processes. South of the George Washington shaft in the southern part of the hills, alaskitic material has spread in anastomosing manner from stratification planes through several adjacent beds converting them completely to alaskite or quartz-orthoclase rock. In other places feldspar dikes appear to fray out and permeate adjacent walls in a manner suggesting replacement.

A lobe of the Coso granodiorite batholith crops out in a small area along the southwest edge of the hills. It is intrusive into the Pennsylvanian limestones, but nowhere can its contact with the stock be observed. No silver-lead mineralization is associated with this intrusive in the Darwin Hills.

The youngest igneous rocks in the hills are the basaltic flows that cap the smoothly truncated surface of Paleozoic rocks in the northern end of the area. These are Quaternary in age and are in no way connected with the metallization of the district.

Structure.—The Darwin stock has a length of five miles and a maximum width of about two-thirds of a mile. From the central part it tapers irregularly into north and south tips, which are only a few tens of feet wide. The general trend, N 25° W, is parallel to that of the sedimentary formations into which it is intruded. In detail its original outline was rather irregular, with many large and small protuberances and outliers. Much of its present irregularity, however, has been caused by subsequent cross faults that have offset the body in many places. In the northern part, the stock is characterized by many inliers of tactite which attest to the proximity and irregularity of its apex in this region (Fig. 3).

Although parallel to the strike of the formations, the stock

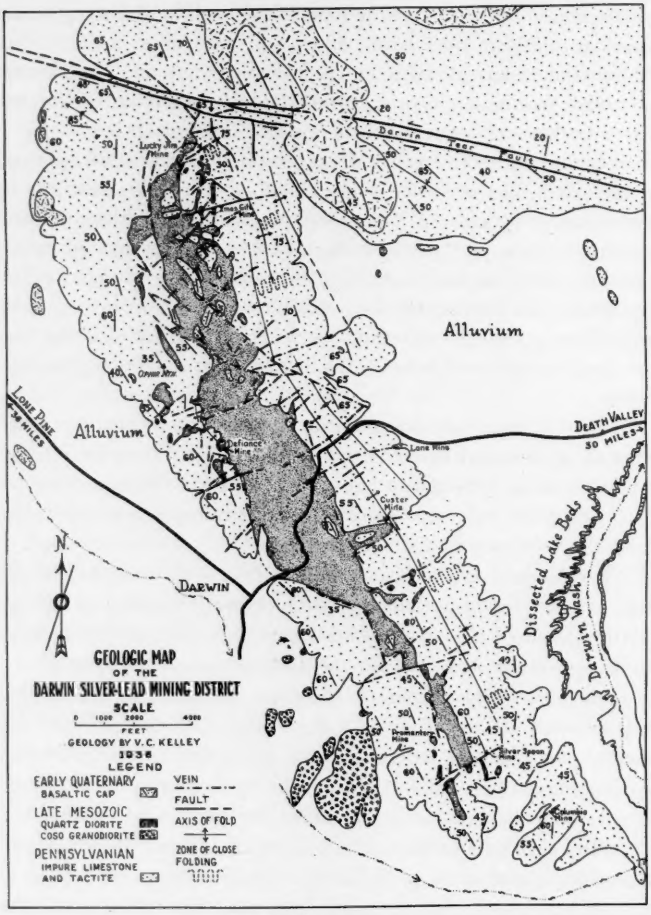


FIG. 3.

transects the west limb of a large fold. The major axis of this large fold lies about 1000 feet east of the stock. The east limb, generally occupying the east slope of the hills, is considerably crumpled into a series of closely spaced nearly isoclinal folds.

The number of small folds lying between the major axis and the east edge of the hills varies from one or two to as many as a dozen. These smaller folds are in the nature of smaller crenulations superimposed upon the larger and broader folds of the region.

A few folds have steeply pitching axes in an east-west direction. These appear as local knots in the otherwise even north-northwest grain of the Pennsylvanian strata. Since the major north-south folds of the region were caused by east-west forces, the smaller folds with steeply pitching east-west axes may have been formed by stresses later directed north and south. Such forces would also have been favorable to the emplacement of the stock that is elongated in this direction. All of the major folds antedate the intrusion of the stock.

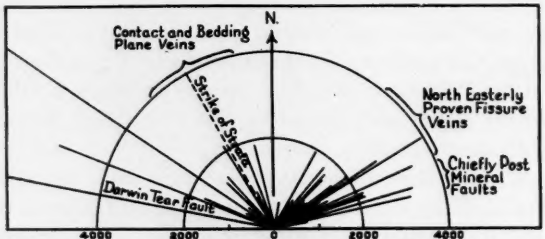
Two systems of fractures, one northeast and the other northwest, cut the rocks of the hills. A few of these may have had their inception prior to the intrusion of the stock. The majority, however, developed and suffered their major displacements in the period intervening between emplacement of the stock and the mineralization or the development of the fissure veins. Some of the fissure veins have suffered post-mineralization movements, and a few unmineralized faults cut the fissure veins. These strike more nearly east west than the fissure veins (Fig. 4).

Of the fissures, those trending northeast, nearly normal to the stock, have proven of most importance. The northwest fractures have the larger displacements, more shearing, and greater width of mineralization. Most of the fissures are developed marginal to the stock and are largely confined to the silicate zone in the limestones. Many, however, extend into the stock and a few cut entirely across it.

The master fracture of the district is here called the Darwin tear fault. It cuts across the north end of the hills and is traceable for at least ten miles on the surface. This fault reveals striking evidence of horizontal movement westward on the north side. As if related to this major break, all of the fractures in the Darwin Hills, whether northeast or northwest, show the same

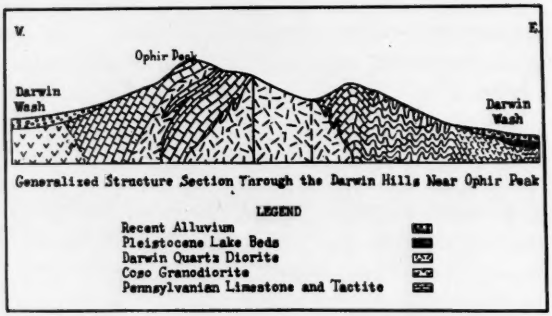
direction of movement. The total effect of the displacements on all of the fractures has been to move the north tip of the elongated stock several hundred feet west of its original position with

A



Analysis of Direction and Magnitude of Faults and of Veins in the Darwin Hills.

B



Generalized Structure Section Through the Darwin Hills Near Ophir Peak

FIG. 4.

reference to the south tip. The displacements on the fractures are dominantly the result of tectonic forces. Many of the fractures may have been initially caused by the forces of intrusion or by those generated during cooling, but these forces played only a very subordinate role in effecting the displacements.

In Quaternary time, basin and range faults trending northwest developed marginal to the range of hills, particularly along the southeast and northwest sides.

IGNEOUS METAMORPHISM.

At Darwin a wide silicate zone or aureole has developed around the stock. The resulting rocks, termed tactites, are whitish, fine to coarse grained, and stratified despite silication. The width of the tactite zone varies from a few tens of feet to nearly 2000 feet. The outer limit of the zone is roughly determinable by the extent of bleaching of the original rocks. An aureole about 1000 to 1500 feet in width is most common.

Wollastonite and garnet are the most common silicate minerals comprising the tactite. In addition, there is considerable calcite, diopside, idocrase, orthoclase, oligoclase, and quartz. The development of this assemblage was accomplished largely by metasomatic action of igneous emanations advancing ahead of and accompanying the emplacement of the stock.

Recrystallization in conjunction with metasomatism was widespread processes at Darwin. The extent of such processes and, in most cases the very existence of them, was dependent upon heat or materials carried by magmatic emanations that permeated great volumes of the Pennsylvanian rocks. Recrystallization with little or no metasomatism took place in argillaceous and arenaceous beds and in marmorization of pure limestones near the contacts. In the calcareous beds including the impure limestones which constitute the great bulk of the Pennsylvanian strata, metasomatism was the dominant agency in the development of the tactites.

Because of the excellent development of the tactites at Darwin and because of lack of space for detailed description here, their petrography and origin and the origin of the altered igneous rocks is described in a separate paper. It will suffice to summarize the evidences and criteria favoring the metasomatic origin of the silicate aureole:

(1) Formation of silicates along the strike of a limestone bed without obliteration of stratification in such a way as to indicate chemically and petrographically that silica was introduced.

(2) Irregular development of tactites not directly related to the igneous contact, and the presence of unaltered impure limestones near some contacts.

(3) Lack of silication adjacent to the Coso batholith in comparison to its extensive development about the Darwin stock.

(4) Garnetization of the intrusive indicating migration of calcium silicates.

(5) Greater development of andradite, showing increase in iron, adjacent to some contacts.

(6) The presence of such minerals as idocrase, tourmaline, apatite, and sphene in the tactites. Especially the presence of idocrase with wollastonite in the initial stages of the development of the tactite.

(7) Veins of calcium silicate such as wollastonite, garnet, and idocrase cutting limestones and tactites.

(8) Veins, dikes, and general impregnation of orthoclase in some parts of the tactite.

Orthoclasization, garnetization, pyritization, carbonatization, and extensive sericitization are the principal alteration effects upon the intrusive.

STRUCTURAL CONTROL OF ORE DEPOSITION.

From the position and nature of the deposits about the Darwin stock it is evident that structure was the dominant control in their location. To some extent the composition of the enclosing wall rocks has had a modifying influence on the local accumulation of ore. There are three types of structural controls: (1) intrusive contacts, (2) bedding planes, and (3) transverse fissures. A single deposit may be localized by two controls or pass from one control into another. Due to the structural relationships shown between the intrusive and country rock in Fig. 4*B* the deposits of the first type are found only along the west contact of the stock.

Deposits along Intrusive Contacts.—The deposits formed at igneous contacts are the largest in the district. Along straight stretches of the contact, deposits of this type may be long, narrow, tabular bodies resembling the fissure deposits. In general, however, the deposits at contacts are lenticular in plan and although shorter in outcrop length than the fissure deposits, they

are mostly thicker. They vary in length along the contact from a few feet to two or three hundred feet Likewise the width may vary from less than one foot to 20 or 30 feet. They extend down irregularly along the igneous surface.

The Defiance and Independence ore bodies are the outstanding examples of deposits along igneous contacts. On the west side of the stock the contact roughly parallels the stratification of the tactites thus forming an effective structural trap along this surface for deposition of ore. Contrasted to this, the east side of the stock bears cross-cutting relationships to the stratification. Hence, the contact surface formed practically no effective trap for the ore solutions which were readily allowed to pass outward along the bedding planes and fractures. As a result of this structural condition there are no mines located on the east contact of the stock. The only productive deposits at the contact are those located on the west side of the stock. The type of ore mineralization and associated gangue is similar or identical to that of many of the bedding plane and fissure deposits.

Bedding Plane Deposits.—Numerous deposits have been formed along the bedding planes, particularly along the east side of the stock where ore solutions found easier avenues of escape from the contact both by reason of more numerous cross fractures and by bedding planes that dip steeply into the contact. The outstanding deposits of this type are the Custer, Jackass, Fernando, and Keystone on the east side, and the upper Defiance and Promontory on the west side. Many of the deposits are sheeted as a result of replacement of several thin beds. Others, such as the Fernando, have formed at the intersection of fissures with favorable stratification planes, and as a result commonly have a chimney-like shape.

In some instances where the igneous contact cuts slightly across the stratification, the contact deposits continue or branch into bedding plane deposits. The Custer and upper Defiance bedding plane deposits are only 20 or 30 feet from the igneous contact. Others, such as the Promontory and the Keystone deposits, are 1000 to 1500 feet from the contact.

Transverse Fissure Deposits.—Deposits of this type are the most numerous in the district, but, although important, it is doubtful that they will be more productive than the deposits formed at the igneous contacts. The fissure deposits are most numerous and important on fractures trending northeasterly, nearly at right angles to the elongate direction of the stock. Many of these are confined to the tactite or extend only a short distance into the intrusive where they are taken up by multiple adjustments along joint planes. Others, such as the Standard or Lane veins, cut entirely across or extend well into the stock. Fissures of this type are mostly vertical, but where inclined the dip is steeply to the north.

Some of the fissures of the above type are intersected by a northwesterly belt of mineralized fissures that lie north and east of Ophir Mountain. The latter are much sheared in places and are accompanied by greater width of mineralization in the form of jasper, calcite, and barite. Metallization, however, is sporadic and the tenor of these veins is as yet unproven.

The Christmas Gift, Lucky Jim, Lane, and Columbia mines are the outstanding producers among the fissure veins. The width of the fissure veins averages two to six feet, but stopes 25 to 30 feet in width have been mined. Ore and gangue mineralization in the fissure deposits is similar to that in the deposits along igneous contacts. Those veins that extend from the tactite into the intrusive show by contrast the influence of the wall rock on deposition. In the intrusive the veins become restricted and ore and gangue scarce and sporadic.

HYPOGENE ORE AND GANGUE MINERALIZATION.

The mineralization that gave rise to the silver-lead deposits at Darwin is sharply set off from the silicate mineralization mentioned above. The silication of the limestones is conceived as having taken place during the emplacement of the stock, whereas the ore and gangue mineralization occurred after the formation of the tactite aureole in subsequent fractures and other structural loci. Quantitatively, the major metalliferous deposition occurred

within the tactites. This post-consolidation mineralization may be discussed in two groups: gangue and ore mineralization.

Gangue Mineralization.—The gangue mineralization consists chiefly of calcite, pyrite, jasper, and fluorite. In addition garnet, orthoclase, quartz, hematite, siderite, and barite are present in lesser quantities. Garnet, orthoclase, quartz, and pyrite are deposited in succession replacing the quartz diorite walls of the Lane vein near the igneous contact in Lane canyon. Again in the Wonder mine 300 to 400 feet from the igneous contact, a similar assemblage is to be found replacing the tactite walls and here coarse calcite and fluorite are intergrown and directly associated with the ore minerals. The occurrence of garnet and orthoclase as post fissuring gangue minerals is quantitatively of minor importance and in by far the majority of deposits calcite, fluorite, jasper, or pyrite make up the earliest formed gangue minerals.

The silicates, garnet and orthoclase, in this instance are of post fissuring origin. They are the result of late silicate solutions and are to be correlated with the numerous small veinlets of garnet, wollastonite, and idocrase found throughout the tactite aureole along small joints and irregular fractures. These vein silicates serve to indicate that the silication period slightly overlapped into the fissuring period. They belong to an intermediate stage, because they are distinctly earlier than the post-fissuring gangue minerals described below.

There is a general decrease in the grain size and abundance of certain gangue minerals with distance from the contact. Extremely coarse calcite in cleavable masses eighteen inches on a side characterize such deposits as the Defiance, Custer, and Wonder, all of which are at or near the intrusive. Farther from the contact, calcite is finer textured and somewhat less common. Rose, green, or white fluorite is a common associate of galena in deposits near the stock, but it is much less common or absent at a distance. Pyrite or its limonite pseudomorph in sizeable pyritohedrons and cubes are abundant in deposits near the igneous contacts. In contrast, the pyrite in deposits at some distance

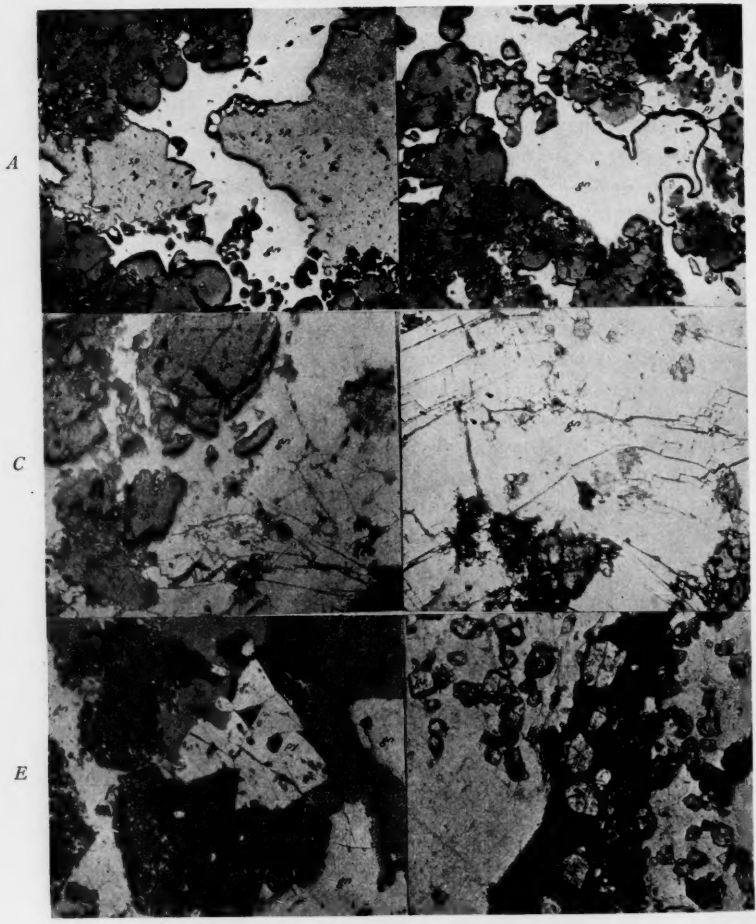


FIG. 5. *A*. Galena (gn) replacement of sphalerite (sp) dotted with chalcopyrite inclusions. Gangue is mostly garnet. 75×. *B*. Galena (gn) replacement of pyrite (py) in a gangue of garnet, calcite, and fluorite. 75×. *C*. Galena (gn) with inclusions of sphalerite (sp), luzonite (l), and tennantite (t). Anglesite (a) is dark gray. Many

from the intrusive is granular, less common, or absent. Jasper is universally present, but is relatively more abundant in those deposits situated some distance from the stock.

Ore Mineralization.—Galena and its oxidation products constitute the principal ore minerals of the district. Galena is found in association with all of the gangue minerals mentioned above and in a few places, as at the Essex mine, it has impregnated and replaced the silicate minerals of the tactite. In places, it is found replacing the igneous rock along fractures. Notwithstanding its varied associations, its dominant occurrence is in lenticular or tabular deposits with calcite, fluorite, pyrite, or jasper or the oxidation products therefrom. Sphalerite and to a lesser extent chalcopyrite occur with galena in many places.

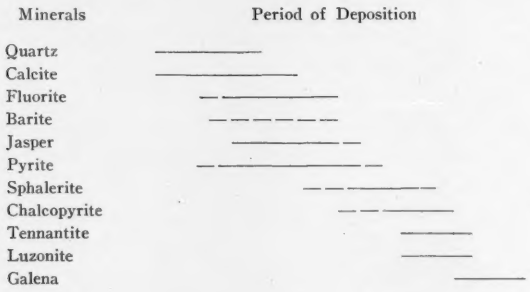
The sulphides are later than the primary gangue minerals. In polished hand specimens from the Rip Van Winkle and the Essex ores small veinlets of pyrite and galena cut quartz, fluorite, and calcite.

Microscopic Features of the Ore.—Specimens were polished of all of the varieties of primary ore that could be obtained in the district. The mineralogy is rather simple and the paragenesis in all of the ores examined, whether from near the intrusive or at a distance, is essentially similar. Galena is the latest primary mineral to form. It replaces all other minerals including sulphides and non metallic gangue minerals alike. It commonly contains numerous inclusions of pyrite, chalcopyrite sphalerite, luzonite, and tennantite. All of these inclusions are clearly residual to the galena replacement. They may occur as individual inclusions or more generally as irregular intergrowths. The sulpharsenides of copper were thought to be the most likely

small feathery veinlets of covellite are present and principally confined to sphalerite or the gray coppers. 75 ×. *D.* Galena (gn) with numerous inclusions of luzonite (l) and tennantite (t). Note the structure of the galena brought out by anglesite replacement along cleavage lines. 75 ×. *E.* Pyrite (py) replaced by sphalerite (sp) in turn replaced by galena (gn). Note the mottled replacement of fluorite (dark) by galena. 75 ×. *F.* Replacement of fluorite (f) by galena (black) with residual metacrysts of diopside (di) and garnet (ga). Transmitted plain light. 75 ×.

carriers of silver values in the galena, but microchemical tests gave no reaction for silver.

The microscopic evidence indicates a sequence of deposition in the following order: pyrite, sphalerite, chalcopyrite, tennantite-luzonite, galena. The accompanying photomicrographs show most of these relationships. Sphalerite commonly contains small spines of chalcopyrite more or less uniformly scattered through it in a manner suggesting an origin by unmixing. The mineral sequence is tabulated below.



ORIGIN AND CLASSIFICATION OF THE DEPOSITS.

The position of the Darwin silver-lead deposits is clearly controlled by the form and extent of the stock. The stock was guided in its emplacement by the structure of the Pennsylvanian strata. Advancing with and ahead of the magma were emanations that carried great quantities of silica and lesser quantities of metals, chief among which was iron.

The introduction of silica into the limestones began at an early stage and continued until the deposition of the sulphides. The early high temperature introductions of silica produced *silication*. However, silica continued to be supplied and under lower temperatures silication gave way to *silicification* in the fissure deposits, first as quartz and later as jasper.

Many of the fissures in and marginal to the stock may have been caused by the pressures of intrusion or the contractional

forces resulting from cooling, but the principal displacements on them are of tectonic origin. The fracturing and movements thereon took place after the intense alteration or silication of the limestones and after the consolidation of the upper part of the stock.

All of the hypogene ore and gangue mineralization came after this period of major fracturing. Thus, the period of fracturing distinctly separates the period of silication in which the tactites developed, from the period of metallization in which all of the ore of the district formed. Some of the movements post-date the period of metallization and have brecciated or offset the ore bodies.

Knopf thought the deposits indicated a "sequence in time" with decreasing temperature as shown by the following statements. "The fissure veins are regarded as representing the low temperature end of a genetically related series of deposits formed at progressively decreasing temperatures," [4] and "the galena ore of the Darwin district began to be deposited under pyrometasomatic conditions, but its maximum deposition occurred at lower temperature," [5] and further, in comparison, "the Cour d'Alene district represents a sequence in space," while "the genetic sequence in the Darwin district represents a sequence in time." [6]

Assuredly a temperature gradient existed away from the intrusive, but this effected only a crude zoning of grain size and, to a lesser degree, of mineralization. Had decreasing temperature determined the place of deposition, it is more likely that deposition would first have taken place at a distance from the intrusive and later, as the temperature fell, at the contact. But there is no indication of long continued deposition of ore with falling temperatures, and temperature was not the controlling factor in the position of the deposits. The simplicity of the ore and paragenesis does not suggest a long continued deposition, and there is no overlapping of mineralization. Instead, the controlling factors were (1) a deep seated supply [6a] of metals and

[4] U. S. Geol. Surv. Bull. 580A, p. 9, 1913.

[5] Ore Deposits of the Western States, p. 552, 1933.

[6] U. S. Geol. Surv. Bull. 580A, p. 10, 1913.

[6a] Holmes, A.: The origin of primary lead ores. Econ. Geol., vol. 32, pp. 763–781, 1937.

their associated gangue substances following the consolidation of the intrusive and the fracturing of the rocks, and (2) the effective opening of fissures, stratification, and contacts to the ore bearing solutions. All of the ore deposition followed the fracturing and was accomplished during a single short period under nearly constant temperature conditions. The only division of the deposits to be made is one of structural control, as already described.

For want of a better example of a pyrometasomatic lead deposit Knopf [7] has chosen Darwin. As evidence of a connection between pyrometasomatic deposits and fissure veins, Knopf [8] cited the Independence ore body as an example of the contact pyrometasomatic type of deposit and the Defiance ore body as an intermediate or transitional link between the contact type and the fissure veins of the district. This conclusion was based on finding apatite in orthoclase associated with primary sulphides at the Defiance mine and andradite garnet with galena at the Independence mine.

These deposits occur near each other along the same intrusive contact and on the whole the mineralization is much the same except that in the Defiance ore body exceedingly coarse calcite is more abundant. Galena and other sulphides have impregnated the tactite to some extent in both deposits, but certainly the association does not indicate that the sulphides formed under the high temperature and pressure that the garnet and orthoclase did. In fact, there is little in either deposit that can be used to set them apart from each other or to set either apart genetically from the fissure veins, especially as regards time, sequence, and substance available from ore forming solutions. In a sense it is better to view them all as fissure deposits. During metallization some fissures were effectively opened along contacts and bedding planes and others along transverse fractures.

The deposits along contacts and in fissures are mineralogically

[7] Ore Deposits of the Western States, p. 552, 1933.

[8] U. S. Geol. Surv. Bull. 580A, p. 9, 1913.

and structurally similar and there is no necessity for demonstrating a transition for they are genetically identical. The fissures have the regularity of strike and dip of mesothermal deposits. The walls are smooth and well defined. Moreover, the regularity and sharp definition of the deposits along contacts compares with that of the fissures. The mineralization directly associated with the deposits is not on the whole of the pyrometasomatic type. Jasper, which is one of the most common gangue minerals in the deposits, is indicative of formation at temperatures attributed to mesothermal deposits. Both fluorite and barite are common minerals of low temperature deposits.[9] During the existence of the pyrometasomatic environment about the stock the characteristic minerals developed were garnet, orthoclase, quartz, specularite, and scheelite, but this mineralization was not extensive. The lead mineralization developed later in a mesothermal environment in association with fluorite, calcite, barite, and jasper. Since the galena everywhere replaces these gangue minerals of intermediate to low temperature type there is no pyrometasomatic galena. It is here suggested that in all probability no pyrometasomatic lead deposits exist by reason of the fact that under high temperature conditions lead-bearing solutions do not deposit lead compounds.

Umpleby,[10] from findings at Mackay, Idaho, and from study of numerous other districts, formulated the generalization that ore about intrusive bodies tends to form on the limestone side of garnet zones. It was his observation that where ore came directly against the igneous contact practically no barren lime-silicate would extend beyond the ore. Darwin appears to be an exception to this, for the silicate rocks in most cases extend far beyond ore bodies at contacts. Of the two contacts, silicate-igneous and silicate limestone, the latter would naturally be more easily penetrated by the ore solutions. Where the silicate zone is wide, stratification well preserved, and fissures common, the rule for-

[9] Lindgren, W.: differentiation and ore deposition. Ore Deposits of the Western States, p. 154, 1933.

[10] University of California Publications in Geology, vol. 10, p. 26, 1916.

mulated by Umpleby would be less applicable because of the preponderance of structural control.

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TALC DEPOSITS OF NORTH CAROLINA.

JASPER L. STUCKEY.

ABSTRACT.

Talc deposits of lenticular shape and irregular size occur in association with the Murphy marble over a length of some 40 miles in the extreme southwestern corner of North Carolina. The marble is one of a series of sedimentary formations of Cambrian age and passes by gradations into the underlying and overlying formations. Along either side of the marble belt the rocks have been intruded by quartz-diorite dikes that are younger than the structures in the enclosing formations. Field and microscopic evidence indicate that the talc lenses were formed by hot solutions of magmatic origin. The quartz-diorite dikes seem to have been the source of the solutions that produced the mineralization.

INTRODUCTION.

TALC deposits of two distinct types have been known in North Carolina for many years. The more widely distributed type is associated with basic igneous rocks such as pyroxenite, dunite and soapstone. Deposits of this nature have not yielded talc in commercial amounts and have received little attention. In the second class of deposits the talc occurs as a series of irregular, lenticular masses associated with marble. These deposits contain important amounts of talc and have been extensively worked; the present study is restricted to them.

Deposits associated with marble are found in the extreme southwestern corner of the state (Fig. 1). Going southwest from Asheville, one finds talc first near Hewitt, in the Nantahala River Valley in Swain county. From this point the marble beds and associated talc lenses continue through the Red Marble Gap along the valleys of Valley and Nottely Rivers across Cherokee county into Georgia. The zone in North Carolina has a length of more than 40 miles and a width that ranges from a few hundred feet to more than one half mile.

Mining was begun in 1859[1] when small amounts of talc were being used as furnace linings at Ducktown, Tennessee. At a later date it was hauled by wagon to Cleveland, Tennesee. With the

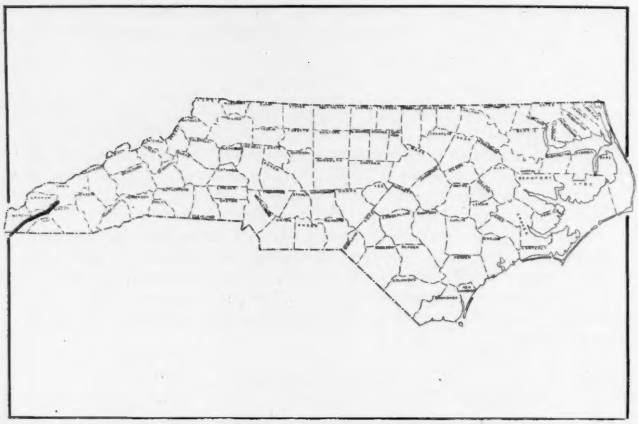

FIG. 1. Outline map of North Carolina showing distribution of marble (black) containing talc deposits.

building of the railroads into Murphy some 50 years ago, mining operations became very active and at one time or another production was made at some 25 localities. Many of these have been abandoned because of the limited size of the deposits or the poor locations with respect to the rivers. During recent years production has been carried on at Kinsey, near Murphy and at Hewitt.

GEOLOGY OF THE AREA.

The talc deposits are associated with the Murphy marble which is one of a series of sedimentary formations of Cambrian age[2] in the area. The marble is underlain by the Valleytown formation and overlain by the Andrews schist. It passes downward into the Valleytown formation by interbedding with the materials of the

[1] Pratt, J. H.: Talc and pyrophyllite deposits of North Carolina. N. C. Geol. Surv. Econ. Paper no. 3, p. 8, 1900.

[2] Keith, Arthur: U. S. Geol. Surv. Atlas, Nantahala Folio, no. 143, 1907.

latter, and grades upward into the Andrews schist through several feet of interbedded marble and schist.

The Murphy marble is a medium to fine grained rock that ranges in color from white to blue. Much of it is banded or mottled in blue and white colors. Small amounts with a beautiful rose-pink color are found in the Red Marble Gap. Analyses [3] from a number of localities indicate that the marble is a normal dolomite.

The underlying Valleytown formation consists mainly of mica-schist and fine-banded gneiss. In places the mica-schist gives way to mica-slate and argillaceous slate. In like manner the gneiss grades into graywacke and feldspathic sandstone. Portions of the mica-schist are rich in garnet and ottrelite crystals.

The Andrews schist overlies the Murphy marble throughout the area except in the northeastern portion, along the Nantahala River, where the Nottely quartzite comes in contact with the marble. The Andrews schist consists essentially of thin bedded calcareous schist. An interesting feature of the rock is that it contains large numbers of ottrelite crystals, which lie at right angles to the bedding planes. Considerable muscovite and biotite are present in the schist and lie parallel to the bedding planes.

The youngest rocks in the area consist of a series of quartz-diorite dikes of post-Cambrian age. They appear at close intervals along both sides of the marble belt along the valleys of Valley and Nantahala Rivers. To the northeast they continue 60 to 75 miles beyond the end of the marble belt and to the southwest for long distances into Georgia. The dikes vary in width from a few inches to 3 or 4 feet and generally lie parallel to the cleavages of the Cambrian rocks but in places cut across them. They are found in all the Cambrian formations except the Murphy marble and are conspicuous in the ottrelite-schist above and below the marble. Keith [4] states that the reason for their absence from the marble is probably due to its being more massive and less easily penetrated than the schists.

The quartz-diorite is composed essentially of quartz and feld-

[3] Pratt, J. H.: *Op. cit.*, p. 22.

[4] Keith, Arthur: *Op. cit.*, p. 5.

spar and has a distinct white appearance. In the groundmass are found well formed crystals of hornblende up to one half an inch long. The dikes are more coarsely crystalline in the center and pass by finer gradations into the schists so that in places it is almost impossible to tell where the diorite ends and the schist begins.

The Cambrian sediments have been altered by dynamic movements to such an extent that their original structure has been almost obliterated and their mineral content considerably changed. In their present condition they consist of marble, quartzite, gneiss, slate, and schist. Enough of their original characters have been preserved, however, to make it possible to work out the structure of the region. The Murphy marble with which the talc is associated occupies a synclinal position throughout its length in the State. The rocks have been subjected to such intense pressure that the limbs of the syncline have been intensely folded and crumpled. Faulting took place along the southeast side of the syncline and it was overturned and older formations thrust up over the Murphy marble throughout most of the area.

GEOLOGY AND MINERALOGY OF THE TALC

The Murphy marble outcrops over an area or belt 40 miles or more in length and from a few hundred feet to over one half mile in width. Some 25 or more talc deposits have been prospected or worked at one time or another in this area. These deposits are all lenticular bodies enclosed in the marble or lying in the marble near its contact with other formations. None have been found that are enclosed in the quartzites and schists either overlying or underlying the marble. The talc bodies are not confined to any portion or horizon of the marble, but are irregularly distributed through it, occurring generally along either side of the outcrop.

The lenses vary in size from a few inches in length and width to masses 50 feet thick or 200 feet long. Some of the lenses are not more than twice as long as they are thick and others are much drawn out and form thin sheets or tabular bodies. The bodies

generally follow the structure of the marble beds in which they occur and lie in all positions from vertical to horizontal. Along the contacts they pass by gradations from pure talc to marble.

The minerals of the lenses in the order of their abundance are: talc, tremolite, carbonates (calcite or dolomite), quartz, hornblende, actinolite, chlorite, and small amounts of pyrite and magnetite. The last 5 of these occur in small amounts in different localities and are of no special importance.

Talc varies in color from bluish-white through pale greenish to white, and in structure from compact to foliated and fibrous. The fibrous structure is commonly pronounced, especially in the talc penetrating the marble. Even the massive talc, when crushed and examined under high magnification, has a fibrous structure.

Tremolite occurs as grains and crystals varying in size from mere specks and needles up to prisms with a diameter of half an inch and a length of 3 or 4 inches. The tremolite crystals may occur as individuals or in radiating bunches and groups. In the talc lenses and associated marble they occur with random orientation and show no relations to the metamorphic structures in the rocks.

Carbonates (calcite or dolomite) make up the marble that encloses the talc bodies. They also occur as irregular masses and lenses, commonly completely separated from the walls and surrounded by talc, within the talc bodies. Some of these masses occur as kidney-shaped lenses, from less than an inch in size to 5 or 6 inches in diameter, completely surrounded by talc or talc and tremolite.

Quartz occurs in the talc deposits in two forms; in the first and minor form it occurs as sand grains. These doubtless represent areas in the original limestone beds where sands were deposited along with the limey materials, which were later folded and metamorphosed into marble, although they may represent only partly replaced masses of silicified marble. In the second form it occurs as vein quartz and masses of silicified marble. On the dump at the Hayes mine, near Tomotla, are masses of vein quartz and silicified marble up to 18 inches in diameter.

A careful study of a number of thin sections cut from specimens taken from various portions of different talc deposits, shows definite relationships among the minerals present. All the minerals found in the area do not occur in every talc deposit, but careful study shows that for those present the same relations always exist.

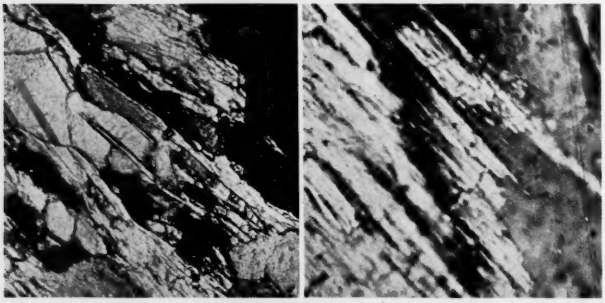

FIG. 2 (left). Talc replacing carbonates. Crossed nicols. × 70.
FIG. 3 (right). Tremolite replacing quartz. Crossed nicols. × 100.

Carbonates (calcite and dolomite) are the oldest minerals present since they form the enclosing marble. Where no quartz is present, carbonates have been replaced by tremolite, or tremolite and talc (Fig. 2). Where quartz is present, it is older than the tremolite and talc and appears to have replaced the marble, forming silicified areas, and to have been deposited as quartz veins. At the Hayes mine masses of cherty quartz contain included grains of carbonates. The masses of quartz, whether silicified marble or vein quartz have been replaced by tremolite (Fig. 3). The dark colored amphiboles, the chlorite, and the pyrite and magnetite appear to have been formed by the same agencies that produced the quartz, tremolite and talc. Talc was the last mineral formed and either replaced the tremolite or in its absence replaced the carbonates directly.

ORIGIN OF TALC.

Talc occurs widely distributed in crystalline rocks such as gneisses and schists and is especially common in dolomitic marbles. It is also found abundantly in metamorphosed basic igneous rocks such as gabbro, pyroxenite and peridotite. Various theories, too extensive to outline here, have been advanced to explain the origin of talc. Ries[5] has stated, however, that it seems safe to say at the present time that the majority of geologists believe that talc has been formed mostly by the action of solutions of magmatic origin.

Pratt's report was the first paper known to the writer in which the origin of the talc deposits associated with the Murphy marble was discussed. He[6] stated that the talc was an alteration product of the tremolite, and pointed out that in the marble walls along the talc bodies are many tremolite crystals entirely altered to talc. He recognized the fact that the tremolite crystals penetrate the marble in radiating fashion with random orientation but offered no suggestion as to their origin.

Keith[7] has discussed the origin of the same deposits in some detail and pointed out that the occurrence of the talc in amounts from mere scales up to bodies 50 feet thick or 200 feet long, many of which are barely twice as long as they are thick, was difficult to explain. He also recognized the fact that the tremolite is irregularly intergrown, in radiating bunches, in the talc and enclosing marble. He evidently considered the tremolite and talc to be due to dynamic metamorphism for he stated: "It is probable that the source of the magnesium carbonates and that of the hydrous silicates are the same, both being derived from the materials of an original sedimentary dolomite."

Gillson[8] has recently studied the Vermont talc deposits in de-

[5] Ries, H.: Economic Geology, 6th ed., p. 407, 1930.

[6] Pratt, J. H.: Talc and pyrophyllite deposits in North Carolina. N. C. Geol. Surv., Econ. Paper no. 3, pp. 12 and 13, 1900.

[7] Keith, Arthur: Talc deposits of North Carolina. U. S. Geol. Surv. Bull. no. 213, p. 434, 1903.

[8] Gillson, J. L.: Origin of the Vermont talc deposits. Econ. Geol., vol. 22, pp. 246–287, 1927.

tail, reviewed the literature and analyzed the conditions of all the more important talc deposits in the United States and some foreign deposits. At the end of his paper he set down a number of interesting conclusions chiefly as follows: 1. Talc deposits are commonly lens-shaped. 2. They are replacement deposits in limestone, schists, gneisses, and in altered basic intrusions. 3. The country rock of the talc was old and probably deeply buried at the time of the talc formation. Dynamic stress was not active in most cases during talc formation. 4. The solutions that formed the talc, whatever the original rock replaced, first formed amphibole, serpentine or chlorite. 5. In most cases the solutions were hot alkaline emanations from granite, diorite or from the acid differentiates of basic intrusions.

Burfoot,[9] in a recent detailed study of the talc and soapstone deposits of Virginia, stated that the talc and soapstone were formed by replacement through the agency of hot solutions of magmatic origin.

Careful studies of all the field and microscopic evidence obtained by the writer indicate that the talc and associated minerals, other than the enclosed carbonates, were formed by the replacement of the Murphy marble by hot solutions of magmatic origin. The evidence for this mode of formation may be stated as follows: (1) the occurrence of the talc in irregular lenses barely twice as long as they are wide; (2) gradational contacts between pure talc and the enclosing marble; (3) the silicification of the marble in some cases before the formation of the talc; (4) the presence of quartz veins at some localities both in the talc lenses and in the marble; (5) the presence of unsupported and completely surrounded lenses of marble in the talc; (6) the presence of radiating bunches and groups of tremolite in the talc and enclosing marble with random orientation; and (7) microscopic evidence of replacement (Figs. 2 and 3).

The sequence of events involved in the formation of the talc bodies is as follows: (1) formation of the Cambrian sediments; (2) metamorphism of the sediments into marbles, gneisses, and

[9] Burfoot, J. D.: Talc and soapstone deposits of Virginia. Econ. Geol., vol. 25, pp. 805–826, 1930.

schists during the Appalachian Revolution; (3) formation of large masses of igneous rocks in the Appalachian region and the intrusion of the quartz-diorite dikes into the gneisses and schists adjacent to the marble; (4) silicification of the marble; (5) development of the tremolite, hornblende, actinolite and chlorite by replacement of quartz and marble; (6) development of talc by replacement of tremolite and marble; and (7) development of pyrite and magnetite with or closely following talc.

The evidence outlined above seems conclusive that the talc was formed by hot solutions of magmatic origin. No large bodies of post-Cambrian igneous rocks are present in or near the area, but small quartz-diorite dikes from a few inches up to 3 or 4 feet wide are abundant in the gneisses, schists, and slates along both sides of the marble belt. As explained by Keith,[10] the dikes are probably present in the schists and slates because of their schistose character and absent from the marble because of its massiveness. The diorite dikes follow the cleavage in part, cut across it in part, and in places branch into layers or run out into thin edges and disappear. The enclosing schists have been strongly silicified and commonly contain veins of quartz younger than their cleavage in areas where the dikes are abundant. They also contain an abundance of garnet which is doubtless a contact mineral due to the effect of the diorite. Ottrelite crystals, which cut across the cleavage of the schists, are also abundant near the dikes, but absent in areas some distance away, indicating further the effect of the diorite on the enclosing rocks.

Nitze and Hanna [11] pointed out that gold bearing quartz veins in Archean rocks are not the only sources of gold in the region. They stated that gold associated with galena had been found in the marble at Section 6, one mile northeast of Murphy, at Axels shaft on Marble Creek, and near the village of Marble. The writer collected materials from the dump of an old shaft on the Section 6 property where it is reported that a gold bearing quartz vein 18 inches to 3 feet thick was worked. The specimens con-

[10] Keith, Arthur: U. S. Geol. Surv. Atlas, Nantahala Folio, no. 143, p. 5, 1907.

[11] Nitze, H. B. C., and Hanna, G. B.: Gold deposits of North Carolina. N. C. Geol. Surv., Bull 3, p. 193, 1896.

sisted of vein quartz attached to marble and contained sulphides in small amounts. Tremolite similar to that in the talc lenses and associated marble was present in the specimens.

The evidence indicates that the massive marbles blocked the rise of the intrusive diorite. Solutions from the dikes, however, reacted with the marble in the immediate vicinity and produced the small irregular talc lenses by replacement of the marble. No diorite has been found in the talc mines. This, however, is to be expected since the marble beds have a thickness of some 500 feet and the talc mines have reached a maximum depth of only about 100 feet.

OPERATIONS AND SUPPLY.

The irregular shape and size of the talc lenses make any attempt to estimate the amount of talc present in the area largely a guess. The soft talc seems to weather readily and many lenses have been found covered with residual mantle, in which only a few fragments of talc were present, or with alluvial soil. This makes it impossible to determine the size of a talc lens until it is largely worked out. It is also probable that many lenses of talc have escaped notice due to the surface covering.

Due to the shape and size of the deposits, mining has been carried on by open pits and shallow shafts from a few feet to 40 or 50 feet deep. Production varies widely from year to year but has been carried on almost continuously for nearly 50 years. The area will, doubtless, continue to produce talc in varying amounts for many years.

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RALEIGH, N. C.,
Sept. 14, 1937.

THE TIN ORES OF BANCA, BILLITON, AND SINGKEP, MALAY ARCHIPELAGO.—A DISCUSSION.

J. WESTERVELD.

ABSTRACT.

This paper is a discussion of an article by Dr. N. Wing Easton that appeared recently in this JOURNAL. The writer is not in agreement with many of the views expressed by Dr. Easton. A resumé of his views is given and evidence is presented: (1) that there is one granite instead of two; (2) that the depth of granitic intrusion and of mineralization was deep instead of practically at the surface; (3) that some contact-metamorphism is actually present; (4) that minor dark intrusives are not known from the tin granites on Banca and Billiton; (5) that the sedimentary ridges are not the result of elevation by younger granite intrusions but result from differential erosion; (6) that the tin mineralization is not Pliocene but is post-Triassic and pre-Neogene, probably pre-Cenoman; (7) that the base levelling (and accumulation of residual tin) was not Mesozoic, but Quaternary, and that the residual tin accumulated under a humid tropical climate; (8) that some zonal arrangement of mineralization does exist.

INTRODUCTION.

A SYNOPSIS of the geology and ore-deposits of the Tin Islands of Banca, Billiton, and Singkep, Netherlands East Indies, has recently been given by Dr. N. Wing Easton in this JOURNAL.[1] It should be considered a welcome effort to draw the attention of all interested to the geology of the interesting primary and detrital occurrences of stanniferous deposits in the Malay Archipelago. This region has been treated rather extensively by mining officials and geologists in Dutch periodicals probably without attracting the attention due it from a wider circle of students of economic geology outside the East Indies, partly because of idiomatic difficulties. The drowned river valleys with their residual tin-bearing bottom layers, covered by alluvial top beds of stratified sands and clays as a result of the regional submergence of the whole

[1] ECON. GEOL., vol. 32, pp. 1–30 and 154–182, 1937.

deeply-eroded area between the larger Sunda Islands (Sumatra, Java and Borneo) in post-diluvial time, will arouse the reader's special interest. A noteworthy feature connected with the geological phenomena to which this region was submitted in Quaternary time is the existence of paying secondary ore-beds at considerable depth below sea level (up to 30 meters and more) on Banca and Singkep. These could be followed in many instances to considerable distances beyond the shore lines and have been exploited by sea-dredges on a large scale especially on Singkep. The separation of the Tin Islands from Java, Borneo and Sumatra took place at the end of the Pleistocene period.

In presenting his personal ideas on the geological history of the Tin Islands and adjacent regions Dr. Wing Easton, however, submits a view on magmatic phenomena and ore-deposition, which deviates considerably from that now almost universally accepted by those familiar with "pneumatolytic" and "hydrothermal" mineralization. Moreover, the explanation of the residual tin ores, from which the bulk of the present production is extracted, and especially the arguments laid down by Wing Easton with regard to the determination of the geological age of these deposits, are not likely to find support among field-workers who have followed the recent progress of geological research in the Netherlands East Indies. It is to be regretted that, in a praiseworthy attempt to instruct a wider circle of geologists about the peculiarities of one of the important tin-producing regions of the world, too little consideration has been given to the vast amount of geological data gathered by the staff of the Geological Survey of the East Indian Government and by geologists working for private companies in the past two decades.

The writer of this discussion in the following lines wishes to criticize only the essential principles put forward by Dr. Wing Easton in his paper with regard to the general geology and features of the ore deposits, without expatiating on points of minor importance. The geological history of the Tin Islands as postulated by Wing Easton is summarized below.

SUMMARY OF VIEWS OF DR. WING EASTON.

1. The dominant plutonic rock of the islands is a mica-granite, hornblende-bearing varieties being of local occurrence. Two generations of granitic rocks are distinguished, one older than the Mesozoic sedimentary sandstone-shale series of the islands, and the other intrusive into the older granite and the sedimentary formation and therefore younger than the latter.

The "younger" intrusive granite is regarded as the parent-rock of the tin-ores.

2. The "younger" granite has been intruded mainly into the central parts of the "older" batholiths, only locally sending off tongues into the sedimentary series, which would explain the scarcity of hornfels on the islands. The "younger" granite is thought to stand out as hard and elevated outcrops surrounded by lower country of soft "older" granite.

3. The sediments are transgressive with regard to the "older" granite, the disintegration products of which are thought to have supplied the material for the sandstones and shales.

4. Practically no signs of contact-metamorphism are present in the sedimentary series along its contacts with granitic rocks (cf. point 2).

5. Intrusive rocks of minor importance are said to be represented by: (*a*) diabase dikes that traverse the granite in each of the three islands and which in part cross the sediments or are bedded in them; (*b*) isolated blocks of quartz-porphyry or liparite and its silicified tuffs on Banca and Billiton, a rock type which would be more common on the islands of the Riau group.

6. The high ridges of sedimentary rocks existing in some parts of Banca (Mt. Maras, 700 m.) and Billiton (Mt. Tadjem, 510 m.) probably owe their existence to the upheaving forces exerted by the "younger" granites.

7. The intrusion of the "younger" stanniferous granite took place at the beginning of the Neogene and the outlines of these "younger" granites are independent of the strike of the sediments.

8. The mineralization connected with the "younger" granites

is thought to have taken place in the Pliocene and to have been limited in its extent mainly to the zones of soft "older" granite and sediments around the hard protruding hills of "younger" granite, which phenomenon is explained by the advanced stage of solidification of this parent magma of the cassiterite deposits at the time of ore formation. To support his conception of the Pliocene age of the mineralization Dr. Wing Easton takes into consideration (*a*) that liparite occurs fairly abundantly in some islands of the Riau group; (*b*) that fragments of coarse granite have been observed in a quartz-porphyry or a related type of igneous rock in the island of Batam; (*c*) that boulders of quartz-porphyry (presumably remnants of dikes) were found on Banca and Billiton, and tuffs of a similar material on Nangka island (N.E. of Billiton); (*d*) that on the island of Telagepat (N.E. of Billiton) nests of quartz, galena, and sphalerite occur in silicified tuffs, all rocks that apparently are considered to be intimately connected with the formation of the primary cassiterite ores and are thought to be Pliocene in age on account of a supposed abundance of late-Pliocene liparites on the neighboring island of Sumatra.

9. The mineralization connected with the "younger" granites is thought to have taken place at shallow depth and even up to the zone of weathering at the time of the cassiterite deposition. In Dr. Easton's opinion the mineralizing agents could get sufficiently permeable outlets into the roof-parts of the batholiths only if the granitic magma rose up close to the present surface, shattering and fissuring the "older" granites and sedimentary rocks above and around it.

10. The islands should have exhibited nearly the same aspect at the time of ore formation by pneumatolytic emanations as nowadays, that is, the rock surface would not have been lowered more than 6–8 meters by subsequent erosion since the Pliocene, which would have sufficed to bring forth the various kinds of residual cassiterite deposits.

11. The low topographic relief prevailing over large parts of the islands is explained as a result of base levelling during Meso-

zoic and perhaps also Palæozoic time, in which periods the "older" granites are supposed to have been thoroughly denuded.

12. A warm and dry climate is accepted for the Neogene, supposed to be the period of intrusion of the "younger" granites. The general upheaval of the islands by the tin-granites is thought to have caused a general lowering of the groundwater table, which caused the weathering of sediments to penetrate still deeper into the superficial zone of the earth's crust. At the time of ore formation, suggested to be of Pliocene age, the climate would have become wetter, so that some vegetation could develop in the valleys, which now carry the residual cassiterite deposits (this to explain the occurrence of fossil tree trunks in the secondary ore beds directly above the bed rock, *e.g.* on Singkep).

13. As regards the mineralogical features of the primary vein deposits on Billiton Wing Easton denies the existence of a zonal arrangement of mineral associations. Except for the oxides, which are considered earlier, the mutual intergrowths of the different minerals in the primary ores would point to an almost simultaneous origin.

14. It is held probable that the tinstone-bearing magnetite outcrops of some ore veins in E. Billiton, *e.g.* the Seloemar [1a] vein, are metamorphous limonite gossans, originally formed by oxidation of pyritic tin ore. The magnetite is supposed to have been formed from the limonite under the influence "of the atmosphere and the sun."

Numerous other questions touched by Dr. Wing Easton in his paper could be submitted to criticism, but the writer will limit himself to those of major importance cited above and treat them in the same order:

DISCUSSION.

1–4. Two Granites (?).—The existence of two generations of granite, one supposed to be older and the other younger than the Mesozoic sediments of the islands, is accepted on merely hypothetical grounds. No unconformity between the probable Triassic sandstone-shale series and a supposed "older" granite,

[1a] "oe" to be pronounced as the English "u".

revealed for instance by the existence of basal conglomerates or arkoses, has ever been found. The base of the sedimentary formations on Singkep, Banca, and Billiton is nowhere exposed. It may be that metamorphosed schists, which form the bedrock in some tin valleys southwest of the large granite mass in the districts of Blinjoe and Soengeiliat in N. Banca, locally constitute the base of the Mesozoic sediments of this largest of the Tin Islands, but no definite judgment can as yet be given about the mutual relations of these two rock series of different ages. It is also not altogether improbable, that the Mesozoic sediments in depth pass into sediments and (or) volcanics of Permo-Carboniferous age over part of the area occupied by Banca and Billiton. In central Sumatra the downward transition of Triassic rocks into a Permo-Carboniferous series has been shown at various spots in the Padang Highlands by Musper.[2] Triassic-Jurassic and Carboniferous formations occur side by side in Upper Djambi, separated by a line of overthrust and pre-Upper Carboniferous granites.[3] On some islands of the Riau group (Lingga, Boelan, Batam) rocks have been found that closely resemble the Pahang Volcanic Series of Malaya and according to investigations in that region, the results of which are still far from satisfactory, they lie at the base of the Triassic sandstone-shale series.[4] That sedimentary rocks older than Trias are present close to Banca is made probable by an interesting discovery of the late Dr. J. van Tuyn, who found pebbles of quartzites, *hornfels, siliceous rocks with radiolaria, crinoids and fusulinae,* hard silicified breccias, *aggregates of tourmaline and quartz, lumps of vein-quartz with distinct cassiterite crystals,* in a conglomerate interbedded between marine glauconitic sand-

[2] Musper, K. A. F. R.: Beknopt verslag over de uitkomsten van nieuwe geologische onderzoekingen in de Padangsche Bovenlanden. Jaarb. Mijnwezen Ned.-Indië, Verh., pp. 265–331, 1929.

[3] Zwierzycki, J.: Die Ergebnisse der paläobotanischen Djambi-Expedition 1925. Jaarb. Mijnwezen Ned.-Indië, Verh. II, pp. 1–43, 1930.

[4] Bothé, A. Chr. D.: Geologische Verkenningen in den Riouw-Lingga Archipel en de eilandengroep der Poelau Toedjoeh, etc. Jaarb. Mijnwezen Ned.-Indië, Verh. II, pp. 101–145, 1925.

stones of the Lower Palembang series (younger Miocene) on the gently arched Palembang-anticline 18 km. W. of Palembang.[5] So, if pre-Triassic granites existed on the Tin Islands one would expect the intercalation of still older sedimentary rocks than Trias between the granites of Banca and Billiton and the Triassic sandstone-shale series, which is not the case.

No convincing evidence is available of the existence of a younger granite phase in the central parts of the granite masses on Banca, Billiton, and Singkep. That the higher tops in the granite regions consist of hard rock exposures and the lower gentler slopes of weathered "soft" granite is characteristic of all granite outcrops that have undergone atmospheric weathering throughout the world. The steeper flanks near the places of highest elevation are washed clean by rainfall and creep, but on the surrounding gentler slopes, denudation is outweighed by weathering and the supply of material removed from higher parts. Marginal zones especially, where "pneumatolytic" and "hydrothermal" alteration has metamorphosed the granitic rocks most strongly, commonly show thorough disintegration of the mineral constituents, and the development of valley cuttings along intrusive granite contacts is, therefore, a common feature. No one, for instance, will pretend that the "tors" of Cornwall (S.W. England) or the hard rocks of Land's End in the same county belong to a younger generation of granite than the soft weathered or kaolinized granite in that region, which has so many features in common with the Malayan Tin Belt. The two examples cited by Wing Easton to support his arguments are far from convincing. If the white, soft granite, poor in quartz from the top of Toemang hill on Singkep forms a sharply distinguishable crust over hard granite rich in quartz, it means only that the granite apparently had a marginal phase richer in feldspar and thereby was perhaps more easily decomposed by weathering. The relations as described by Dr. Wilhelm[6] from this mineralized granite

[5] Quarterly Report of the Mining Department. Javasche Courant, No. 80, Oct. 7, 1932.

[6] Wilhelm, Ch. H. J.: De Tinertsafzettingen van het Eiland Singkep en de Genese der Alluviale Afzettingen, pp. 21–33. Diss., Delft 1928.

outcrop on Singkep, however, do not offer any evidence of a different age of these two phases of granitic rocks. To the granite of Boekit Besi in N.E. Billiton, where elevated outcrops of hard granite are surrounded by soft kaolinized granite, the general principle of the struggle between denudation and weathering is applicable, although the possibility of some hypogene kaolinization cannot be excluded.

Depth of Intrusion.—A thesis that is totally untenable is the conception of a younger granite having penetrated into an older granite up to its weathered crust, which was formed after a preceding period of deep denudation. This means that the parent-rocks of the tin ores during intrusion would have reached the actual surface of the earth. This is a point that hardly needs serious discussion, as the congealing of a coarsely crystalline porphyritic rock with phenocrysts measuring 5 cm. and more, streaks of pegmatite, and similar in petrographic and chemical properties to tin granites of the classical regions in Europe and elsewhere,[7] would be a novelty in geological science. If the intrusive "younger" granite had risen to such extremely shallow depth as suggested by Dr. Wing Easton, they certainly would show a glassy matrix and be accompanied by surface-flows, ashes, etc., which thus far have not been detected on the islands.

Contact Metamorphism.—The supposed scarcity of hornfels along the margins of the granite masses, explained in accordance with the conception that the sedimentary series is nearly everywhere in contact with the "older" granite, is easily explicable by the simple fact of the scantiness of exposures. The boundaries between granite and sediments are always marked by low ground covered by a thick regolith, so that direct observations of contact relations can only occasionally be made. Where, in rare places, a contact has been laid bare, as for instance on the beach near Cape Kedamin in the Toboali district[8] and near Cape Pahit in

[7] Westerveld, J.: The granites of the Malayan tin-belt compared with tin-granites from other regions. Kon. Akad. van Wetenschappen te Amsterdam, Proc., vol. 39, pp. 1199–1208, 1936.

[8] Verbeek, R. D. M.: Geologische Beschrijving van Bangka en Billiton. Jaarb. Mijnwezen in Ned. Oost-Indië, pp. 49–52, 1897.

the Muntok district,[9] both on Banca, the slates have been found converted into hornfels. The writer, in studying the western section of the great batholith of North Banca in the Djeboes district, did not meet with any favorable spot where the granite could be seen in contact with the sedimentary series; yet all other evidence was sufficient to prove the intrusive nature of this rock.[10] No indication whatever has been found of the existence of two granites in that region. The numerous excellent exposures along the coast of N. Banca all show only one uniform rock type, a coarse porphyritic biotite granite with well defined sets of joints, commonly occupied by tourmaline veinlets, over its whole area. Only towards the margins, as near Cape Penjaboeng and on Kambing island in Klabat Bay, a marginal phase with finer grain was observed. It should also in this connection be recalled to the mind that the uniform habit and intrusive nature of all the larger tin granites on Banca has already been well recognized by the first mining engineers working on this island. Their reports, accompanied by rather accurate geological maps and published in the „Jaarboek van het Mijnwezen" between 1872 and 1885, in many instances mention the alteration by contact metamorphism of the sediments near the granite contacts in the regions of residual tin ores, such as silicification, pyritization, etc.

The existence of granite material in the sandstones of the sedimentary series (quartz grains with undulating extinction, fragments of microcline, etc.) proves only that the Mesozoic series received its material from an older land mass, which, however, need not be exposed at the present land surface. The Pahang Volcanic Series of Malaya, thought to be a volcanic equivalent of the Carboniferous to Triassic sediments of the Peninsula, is known to contain boulders of granite on Pulau Nanas, not far from Singapore.[11] Likewise, pebbles of a sheared granite have been found in a Triassic conglomerate on Pulau Sambo, in Riau

[9] Quarterly Report of the Mining Department, in the Javasche Courant of January 12, 1934, No. 4.

[10] Westerveld, J.: On the geology of North Banca (Djeboes). Kon. Akad. van Wetenschappen te Amsterdam, Proc., vol. 39, pp. 1122–1131, 1936.

[11] Scrivenor, J. B.: Geology of Malaya, p. 49, 1931.

Archipelago.[12] Both occurrences only demonstrate the existence of a buried older granite which has not yet been exposed by denudation.

5. *Minor Intrusives.*—With regard to intrusive rocks of minor importance, the data furnished by Dr. Wing Easton are rather inaccurate. Diabase dikes traversing the granite have thus far been described only by Wilhelm from Singkep.[13] It may be that similar occurrences will be found on Banca and Billiton, but the diabases hitherto known from these two islands lie outside the granite areas. The diabase from Cape Penjaboeng in Djeboes on Banca was found by the writer to be a basic forerunner of the granite, which exerted a rather strong pneumatolytic action on the former rock (uralitization of pyroxenes, etc.). The existence of "liparite and its silicified tuffs" on Banca and Billiton has not been proved conclusively. A hard dark-greenish and scaly rock with large crystals of quartz, some feldspar, and uralitized pyroxene in a matrix of small quartz individuals, bright green amphibole, brown mica, ilmenite, titanite and some pink zircons from the hill below the old Toboali fortress, S. Banca, has been called a silicified porphyry tuff by Verbeek, but the description is too incomplete to justify this denomination. It might as well be a hornfels, originated under influence of the neighboring intrusive granite. The description of rocks from the islands of the Nangka group northeast of Billiton (P. Nangka and P. Telagepat), called silicified porphyry breccias and tuffs by the same author,[14] in the same way is too vague to enable any conclusion to be drawn about their origin. From Billiton itself, no statement of the occurrence of acid effusive rocks and tuffs is known to the writer. A comparison of these rather vaguely described rock types from Banca and Billiton with liparites and their tuffs from the Riau Islands, found by Bothé [15] on P. Batam and P. Lingga, therefore, cannot be made without further careful investigation.

[12] Bothé, A. Chr. D.: Brief outline of the geology of the Rhio Archipelago and the Anambas Islands. Jaarb. Mijnwezen in Ned.-Indië, Verh. II, p. 98, 1925.

[13] Wilhelm, Ch. H. J.: Op. cit., pp. 10–15.

[14] Verbeek, R. D. M.: Op. cit., pp. 78–79, 93–95.

[15] Bothé, A. Chr. D.: Op. cit., pp. 122, 127.

6. Ridges Elevated by "Younger" Granite.—The high ridges of sedimentary rocks existing in some parts of Banca and Billiton, that are presumed to owe their existence to elevation exerted by the "younger" granite, are simply hard banks of sandstones or rocks hardened in some way by hydrothermal processes (silicification, pyritization and subsequent hardening by alteration into hard ferruginous slates or sandstones) and projecting from their environment as a result of differential erosion. A glance at the geological map of Banca in Verbeek's work clearly shows the alignment of sedimentary ridges in the direction of the strike of the strongly folded sandstone-shale series. The upturned position of the sandstones and shales has been caused by orogenetic movements in post-Triassic time, which were followed closely by the intrusion of the tin granites. The latter phenomenon is a natural consequence of the former, but not the reverse.

7–8. Age of Intrusion and Metallization.—About the age of the granitic parent rocks of the cassiterite deposits and the attending mineralization, it is known only that they are in any case post-Triassic and pre-Neogene, very probably pre-Cenoman. No rocks younger than Trias have ever been found among the strongly folded sediments of Malaya and the Tin Islands, which would allow a more exact determination of the age of the intrusive granites. Pebbles of cassiterite-bearing quartz and tourmaline-quartz rock have been found in conglomerates of the Miocene Lower Palembang series near Palembang on Sumatra as mentioned before. The Neogene oil-bearing strata of Palembang are only gently folded on the east side of the petroliferous belt and are not indurated to the degree exhibited by the strongly folded Mesozoic sedimentary series on the islands east of Sumatra. They contain layers rich in beautifully preserved Miocene lamellibranchiates near Palembang town. Southeast of this city the base of this fossiliferous Miocene series is exposed around Mt. Batoe, a hill rising about 41 m. above the surrounding marshy landscape and consisting of a grano-syenitic rock, which on close examination yielded some cassiterite and by its high K_2O content shows a marked relationship to some potas-

sium-rich rock types of the Inner Malayan petrographic province.[16] So here there is a direct observation on the unconformity between Miocene sediments and the rocks of the tin belt. The early-Miocene transgression, conspicuous over large parts of Sumatra, has possibly also reached locally the Inner Malayan region east of this island. On the islands of Batam and Bintan of the Riau group, sandstones have been found unconformably resting upon folded Triassic sediments.[17] Unfortunately nothing is known about their true age. On the west side of the Malayan Peninsula, patches of a formation consisting of shales and sands and containing seams of lignite have been found in Selangor and Perak. They are younger than the tin granites and may be of late-Tertiary age, possibly, however, even younger than Miocene. Their exact age in the same way cannot be given.[18]

The arguments put forward by Dr. Wing Easton to prove a Pliocene age of the mineralization do not take into account any of the observable facts cited above and are based upon mutually contradictory data. Liparites from the Riau group, which form part of the folded Triassic and perhaps in part older, strongly folded series of these islands, are drawn together with a post-Triassic but certainly pre-Neogene quartz-porphyry from the island of Batam and with "late-Pliocene" liparites supposed to occur abundantly on the neighboring island of Sumatra. Apart from the fact that this comparison does not succeed, the occurrence of certainly late-Pliocene liparites on Sumatra is not known to the writer from literature or personal observation. As a matter of fact the folded Pliocene Upper Palembang series consists mainly of rather acid pumice-tuffs, but is not known to contain lava flows. The foci of eruption, from which this material has been derived, have not been deducted. The visible liparitic rocks from this island are perhaps largely early-Quaternary and to a minor degree sub-Recent. In southern Sumatra, where acid effusives have become rather extensively known during the re-

[16] Van Tongeren, W.: Mineralogical and chemical composition of the syenite-granite from Boekit Batoe near Palembang, Sumatra, Netherlands East Indies. Kon. Akad. van Wetensch. te Amsterdam, Proc., vol. 39, pp. 670–673, 1936.

[17] Bothé, A. Chr. D.: Op. cit., pp. 99, 145.

[18] Scrivenor, J. B.: Op. cit., pp. 114–117, 1931.

cent survey of the residencies of Lampoeng Districts, Benkoelen and Palembang, these rocks are mostly connected with long fault lines along tectonic depressions that follow the main trend of the island and are conspiciously developed east of the Barisan Mountains, which constitute the main divide between the river systems of the Benkoelen coast and those flowing towards the large hilly plains of Palembang and to Semangka Bay. The principal movements and eruptions of effusives along these longitudinal fault lines certainly took place in post-Pliocene time and were synchronous with the upheaval of the Barisan mountain block, which consists mainly of strongly folded Miocene sediments and volcanics of the so-called Telisa and Lower Palembang series. The former and older of these Miocene series is intruded by late-Miocene dioritic, granodioritic, granitic, and dacitic rocks and covered unconformably by the tuffaceous marine Pliocene deposits of the coast section of Benkoelen and by mixed Quaternary andesitic material.[19] To these early-Quaternary dacitic and liparitic flows, using lines of rupture as canalways, belong the perlitic lavas of the fissure eruptions along the Semangka valley in the western Lampoeng districts [20] and also the extensive liparite-flows of the deeply dissected Pasoemah plateau south of the Goemai Mountains. These can be followed from the Benkoelen-Palembang boundary south of Mt. Dempo down to the eastern margin of the Goemai Mts. south of Lahat [21] and cover the folded Neogene Palembang layers (*i.e.* the Telisa series) almost horizontally and unconformably. In northern Sumatra the liparites around Lake Toba likewise have erupted along post-Tertiary fault-lines, to which the Toba depression owes its present outlines.

To conclude this digression on the incorrectness of Dr.

[19] Compare sheets 3 (Bengkoenat) and 6 (Kroeï) of the Geological Map of Sumatra (scale 1 : 200,000) with explanations (Dutch) resp. by J. Westerveld (1933) and R. W. van Bemmelen (1933), and also the annual reports of the Geological Survey in Jaarb. Mijnwezen in Ned.-Indië, Algemeen Gedeelte, 1931 (pp. 24–39) and 1932–1933 (pp. 5–12).

[20] Van Bemmelen, R. W.: Op. cit., pp. 37–41.

[21] Unpublished report by the writer. A. Tobler wrongly synchronized the liparite of the Selangis River southeast of the Goemai Mountains, which forms a part of the Pasoemah liparite flows, with the Pliocene Upper Palembang layers, (Tobler, A.: Geologie van het Goemaigebergte, Jaarb. Mijnwezen, etc., Verh., p. 44, 1912).

Easton's view regarding the age of the granites and attendant mineralization on the Tin Islands, it should be emphasized that a comparison of igneous rocks from the Inner Malayan Arc with the much more complex zones of eruptive rocks of the Sumatran mountain ranges is not justified on the scant data supplied in his paper. From the investigations of Tobler, Musper, Zwierzycki, and the recent systematic survey of S. Sumatra we know of the existence of at least three and possibly four generations of granites and allied rocks in middle and southern Sumatra. In the Lampoeng districts there are gneissic granites of undetermined age, intruded by younger pre-Neogene granites.[22] Upper Djambi and perhaps also Upper Indragiri have pre-Upper-Carboniferous granites.[23] Post-Triassic, but pre-Neogene granites are known from the Padang Highlands, west coast of Sumatra,[24] and numerous pre-Neogene granites are intrusive into the Triassic-Jurassic slate formation of Upper-Djambi.[25] In the Goemai Mountains of Upper Palembang granitic rocks intrude steeply folded Cretaceous sediments, but are covered unconformably by early-Miocene and perhaps older andesitic tuffs and sandstones;[26] also, in the Barisan Mountains of Benkoelen near the west coast there are the numerous intrusions of late-Miocene granites mentioned above. So if Dr. Easton's method of comparison were to be applied to determine the age of the intrusive rocks on the Tin Islands one would have the choice between granites of very different ages on Sumatra, whereas the mineralization on Banca, Billiton, etc., could be transferred to the Quaternary, the period of liparitic eruptions on the larger island. That this method of reasoning is devoid of scientific basis goes without saying.

The only region where we find contacts that might fix the age of

22 Westerveld, J.: Explanation to sheet 5 (Kotaboemi) of the Geological Map of Sumatra, scale 1 : 200,000, 1931 (Dutch).

23 Zwierzycki, J.: Op. cit. Musper, K. A. F. R.: Indragiri en Pelalawan. Jaarb. Mijnwezen in Ned.-Indië, Verh. I, p. 181, 1927.

24 Musper, K. A. F. R.: Op. cit., 1929.

25 Tobler, A.: Djambi-Verslag. Jaarb. Mijnwezen in Ned. Oost-Indië, Verh. III, p. 361, 1919.

26 Musper, K. A. F. R.: Nieuwe fossielresten en de ouderdom der kalksteenen in het Pretertiair van het Goemaigebergte. De Ingenieur in Nederlandsch Indië, vol. 4, p. 134, 1934.

the tin-granites on the islands east of Sumatra (and on Malaya) more precisely, is in S.W. and N.W. Borneo, where the mountain system of the tin belt continues respectively into the Mesozoic ranges of the Schwaner Mountains and the area between S.W. Serawak and the lower Kapoeas river. The Schwaner Mountains consist of strongly folded Mesozoic (possibly largely Triassic) sediments resembling the sandstone-shale series of Billiton, which are intruded by large batholiths of granitic rocks.[27] Along their northern margin the rocks of the Schwaner Mountains are covered unconformably over long distances south of the Melawi and Kapoeas rivers by conglomerates and feldspathic sandstones of the very probably Eocene transgressive Melawi formation,[28] so that for S.W. Borneo it is certain that the age of the large batholiths is at least pre-Eocene. The geology of the Pontianak division between the lower Kapoeas and S.W. Serawak has been studied more thoroughly and the existence of Triassic, Jurassic and Cretaceous sediments is known. In S.W. Serawak, sandy shales with *Monotis salinaria* show an apparently conformable downward transition into a partly volcanic series with intercalated fusulina-limestones and tuffaceous shales with *Chonetes sp., Strophomena sp.*, and *Orthis sp.*, so that the base of the Mesozoic series in N.W. Borneo very probably lies conformably upon Permo-Carboniferous rocks, which can be compared with the Pahang Volcanic Series of Malaya.[29] The lower part of the Mesozoic series containing Triassic and Jurassic elements is intruded by large granite batholiths and allied rocks (diorites, etc.) in the administrative subdivisions of Sanggau, Landak, Singkawang, and Mampawah. Cretaceous rocks with *Orbitolina concava* have been found to cover the older Mesozoic sediments and granites unconformably, *e.g.* along the Kembajan river in Sanggau, where the base of this

[27] Compare the summary description by L. J. C. van Es: Explanatory text to sheet IX (West-Borneo and Billiton) of the geological outline-map of the Netherlands East Indies, scale 1 : 1,000,000; Jaarb. Mijnwezen in Ned. Oost-Indië, Verh. II, pp. 1–35, 1918 (Dutch).

[28] Jaarb. Mijnwezen in Ned.-Indië, Algemeen Gedeelte, p. 51, 1931 (annual report on the geological explorations in West-Borneo).

[29] Krekeler, F.: Over een nieuw voorkomen van fossielhoudend Palaeozoikum in Midden-West Borneo. De Mijningenieur, p. 167, 1932.

transgressive sandy series is formed by a conglomerate with boulders of granite.[30] Recent investigations by the Borneo party of the Geological Survey have demonstrated that the orbitolina-bearing Cretaceous of this region is everywhere transgressive with regard to the older Mesozoic sediments with their intrusive granites, and that from northwest to southeast the exposed divisions of the pre-Cretaceous Mesozoic increase in age. Also in the upper Kapoeas region, south of the great lakes, the orbitolina-bearing Cretaceous covers unconformably [31] the older sedimentary formations, *e.g.* the possibly Permo-Carboniferous "Tuffite" series of the upper Bojan and Embahoe rivers. Because the mountain systems of S.W. and N.W. Borneo may be assumed to form part of one broad orogenetic belt it seems warranted to accept a pre-Cenoman and possibly post-Jurassic age for the large granite batholiths of these regions and also for the granites of the Tin Islands, which certainly were intruded during the same period of diastrophism.

9–10. Depth of Mineralization.—Being compelled to accept consolidation at least at moderate depths for the coarsely crystalline and mostly porphyritic granites of the Tin Islands, it becomes self evident that the mineralization following closely upon the formation of an outer solid shell of some thickness must have taken place at about the same level below the earth's surface. The primary cassiterite occurrences on these islands, which have been best studied on Billiton, are all of the pneumatolytic and hypothermal type. In the intrusive granites, cassiterite occurs in greisen and tourmaline associations with locally abundant topaz

[30] Van Es, L. J. C.: Op. cit., pp. 16–21, 23–24. Wing Easton, in his monograph on the region between the Sambas and Kapoeas rivers in N.W. Borneo (Geologie eines Teiles von West-Borneo, etc.; Jaarb. Mijnwezen in Ned. Oost-Indië, Wetenschappelijk Gedeelte, p. 369, 1904), accepts a pre-Triassic age for the large granite of Mempawah and Landak, however, without convincing arguments. This view is very certainly incorrect, as the granitic rocks surely have been observed to be surrounded by aureoles of contact-metamorphism in the Mesozoic slate formations, a fact already duly recognized by C. J. van Schelle about 1884 (van Schelle, C. J.: De Geologisch-Mijnbouwkundige Opneming van een gedeelte van Borneo's Westkust, etc. Jaarb. Mijnwezen, etc., II, p. 286, 1884; and Technisch en Administratief Gedeelte, p. 121, 1886). Van Es also shares van Schelle's view.

[31] Jaarb. Mijnwezen, etc. Algemeen Gedeelte, pp. 54–55 and 58, 1931.

(N. Billiton, Banca) and only minor amounts of hydrothermal sulphides of the base metals. The cassiterite-bearing lode deposits of Billiton, all lying within the strongly folded sedimentary sandstone-shale formation, show an abundance of rather coarsely crystalline pyrometasomatic minerals such as fayalite (Seloemar vein), garnet, pyroxene, amphibole, biotite, and magnetite. The last mineral sometimes occurs in large masses as in the Seloemar and Batoe Besie veins, whereas it forms a regular constituent in the Klappa Kampit ore field. The lode material contains a large amount of sulphides such as pyrrhotite, arsenopyrite, pyrite, sphalerite, chalcopyrite, galena, and also siderite and fluorspar. The ores display a massive appearance and are different from ores formed at shallow depths. Those cassiterite deposits for which deposition under shallow conditions has been accepted with good reasons, *i.e.* the tin-silver deposits of the Potosi-Poopó and Uncia types in Bolivia, which form systems of branching veins in and around necks of quartz-porphyry, contain tin ores of very peculiar and different textures and compositions. From the descriptions of Ahlfeld [32] and others it is known that in accordance with their mode of origin, which implies a rapid passage of the metallizing agents and a quick rate of cooling, these occurrences show in some instances pronounced "telescoping" of mineral zones (Uncia-Llallagua), colloform mineral aggregates, development of cassiterite in forms called needle-tin and wood-tin, in association with low-temperature argentiferous sulphosalts (Potosi, Oruro) or with a metastable mineral such as wurtzite (Poopó). Even with these deposits the present topography is thought to lie at least some 200–500 meters below that existing at the time of ore deposition. None of the enumerated characteristics are found in the primary deposits of the Tin Islands, neither on the Malayan Peninsula nor in Burma. An exact figure for the depth of formation of the Malayan tin-ores cannot be given; it is probably more of the order of some thousands of meters than of some hundreds. That Banca and Billiton should have exhibited nearly the same aspect at the time of ore formation as nowadays is, therefore, an unacceptable hypothesis. The

[32] Ahlfeld, F.: The Bolivian tin belt. ECON. GEOL., vol. 31, pp. 48–72, 1936.

present land-surface is the result of long continued erosion since late-Mesozoic (presumably pre-Cenoman) time and the typical topographic features of the Tin Islands with their drowned valleys developed only in the last stage of this period of denudation —that is in Quaternary time.

11. Age of Base Levelling.—Concerning the base leveling, by which the islands were slowly reduced to their present gently undulating topography, Dr. Easton confounds cycles of erosion of two different ages and following periods of diastrophism, which in geological history may have been as far apart as the pre-Carboniferous and the late Mesozoic. The supposed "older" granites, which as far as known, do not outcrop anywhere on the islands, certainly may have been subjected to erosion during Palæozoic and Triassic time. Along the whole Inner Malayan Arc the Triassic sediments are, however, strongly folded, which means that the base-levelling work of an old cycle of erosion was again interrupted by younger and presumably late-Mesozoic (pre-Cenoman) mountain-building forces. The present orographic features of the whole southeastern Asiatic tin belt have developed since the latter period of diastrophism and attendant granite intrusions and metallization. Their formation has nothing to do with denuding forces, which were active in Triassic and older times.

12. Climatic Conditions.—The climate during the Palæogene and Neogene need not be considered to explain the development of the residual cassiterite deposits. The products of disintegration formed in Tertiary time have long since been swept away from the present land-surface of the Tin Islands and presumably are lying now somewhere on the inundated Sunda shelf or on the bottom of the South China Sea. Only in Quaternary time did the topography receive its present modelling and the processes of weathering, chemical leaching, and bottom-slope creep, by which the exploited residual and alluvial deposits were formed, must be transferred to the very last stages of the still active post-orogenetic cycle of erosion, as has been emphasized convincingly by Dr. J. W. H. Adam in an interesting essay on the genesis of

the residual cassiterite deposits.[33] Remains of the Sumatran elephant have been found in a residual cassiterite-bearing sand (a so-called "kaksa") resting upon folded Triassic bedrock in the district of Soengeiliat, N. Banca,[34] so that the residual deposits are probably even younger than Pleistocene. That the formation of the deep regolith over the sedimentary series and over the intrusive granites has substantially been promoted by the wet tropical climate need not be explained to the reader who has observed the contrast between deeply weathered soils in humid tropics and the fresh appearance of rocks in arid regions, where denudation operates chiefly by mechanical agencies. The great productiveness of some cassiterite-bearing contact zones between intrusive granite and sediments along Kinta Valley in Malaya according to Mr. J. B. Scrivenor[35] certainly must be ascribed to the deep weathering of the rocks under humid tropical conditions. This, of course, also holds for the extensive residual eluvial deposits on both granitic and sedimentary rocks on the Tin Islands.

13–14. Zonal Ore Distribution.—A zonal arrangement of the mineralization, denied by Dr. Easton, certainly exists to some extent on Banca and Billiton. In the intrusive granite cassiterite is associated with black tourmaline, topaz, white mica, in places wolframite, rarely molybdenite, quartz, and only minor amounts of sulphides of iron and the base metals. The association of cassiterite-tourmaline-quartz and other high-temperature assemblages, as for instance the pyrometasomatic silicates of the tin lodes on Billiton, are also developed in sediments outside of the granite contacts, but the bulk of the sulphides is found in the sandstone-shale series. The sulphidic tin ores from Billiton have been mentioned, and on Banca the relations seem to be quite the same. The limonite-capped hills along the granite boundaries on the latter island are well known and represent gossans of sulphide impregnations (perhaps mainly pyrite) in the sedimentary series.

[33] Adam, J. W. H.: Kaksa-Genese. De Mijningenieur, p. 217, 1932; pp. 20 and 81, 1933.

[34] Martin, K.: Ueberreste vorweltlicher Proboscidier von Java und Bangka. Jaarb. Mijnwezen Ned. Oost-Indië, Wetensch. Gedeelte, pp. 285–308, 1884.

[35] Scrivenor, J. B.: The geology of Malayan ore deposits, pp. 152–153, 1928.

In the granite these prominent ironstone hills are totally or almost totally absent. The minerals of the primary ores are by no means of simultaneous origin. The silicates of the Klappa Kampit ore field on Billiton are earlier than magnetite, cassiterite, and pyrrhotite, and the latter minerals are again followed by chalcopyrite and sphalerite, and siderite, the latest formed. Amphibole has been observed to develop from pyroxene.[36] This order agrees well with paragenetic relations in pyrometasomatic-hypothermal ore types from other regions, as is to be expected.

The magnetite outcrops of some of the Billiton lodes, *e.g.* the Seloemar vein, are certainly not an alteration-product of original limonite-gossans, but primary high-temperature ore formations as in all pyrometasomatic and hypothermal mineral deposits of the world that contain magnetite. As stated above, this mineral occupies a definite position in the order of mineral deposition and is earlier than the sulphides of the base metals. The occurrence of magnetite in the Seloemar vein is not limited to the outcrop as Dr. Easton says. Downward development of this deposit proved the existence of primary sulphidic ore with cassiterite, pyrrhotite, chalcopyrite, sphalerite, and galena on the second level adjacent to a curious body of fayalite against the foot-wall. On the third level, cassiterite-bearing magnetite again takes the place of fayalite and sulphidic ore.[37]

CONCLUSION.

The Tin Islands belonging to the Netherlands East Indies (Singkep, Banca, Billiton, etc.) geologically form a normal link in the late-Mesozoic (probably pre-Cenoman) mountain-chain, which extends southeastward from eastern Burma through lower Siam, the Malayan Peninsula, the islands east of Sumatra down to Banca, and from thence eastward over Billiton into the south-

[36] According to a microscopical study of these ores by Dr. J. W. H. Adam, Chief Geologist of the "Gemeenschappelijke Mijnbouwmaatschappij Billiton," summarized in a short note accompanying a collection of Billiton ores at the Mineralogical-Geological Institute of Utrecht University, kindly given for perusal to the writer.

[37] Data from Dr. J. W. H. Adam in his note accompanying the collection of the Mineralogical-Geological Institute, Utrecht University.

west part of Borneo. In a broader sense the islands between Malaya and Borneo, the Anambas Islands, Natoena Islands and Karimata Islands, and the Mesozoic mountain ranges of N.W. Borneo, also belong to this orogenetic unit. A monotonous series of Triassic sandstones and shales constitutes the main sedimentary formation on the islands of the Riau group and on Banca and Billiton. The sandstones contain granitic material (quartz grains with undulatory extinction, microcline, etc.) from an old landmass, which, however, lies buried below younger sediments and intrusives at the present time. A conglomerate with pebbles of sheared granite was found in this series on Pulau Sambo, Riau archipelago. The existence of Mesozoic rocks younger than Trias has not been proved. Other pre-Quaternary sediments than Trias are represented by sandstones of possibly Tertiary (Neogene?) age on Bintan, which cover all older formations unconformably and are post-granitic.

Pre-Triassic rocks are probably represented by liparites and tuffs on some islands of the Riau group (Bintan, Batam, Lingga), which have been compared with the Pahang Volcanic Series of Malaya. The true relation between these volcanics and the sedimentary Triassic series is, however, insufficiently known. In N. Banca true schists have been found in the districts of Blinjoe and Soengeiliat. Their position with regard to the Triassic series has not been observed. This appearance of metamorphic rocks in the midst of the sandstone-shale series is probably due to some tectonic cause, *e.g.* imbricated structures.

All other igneous rocks than those mentioned above are intrusive into the sedimentary series and are closely connected with the late-Mesozoic diastrophism, during which the Triassic and older sedimentary strata of the inner Malayan region were strongly folded. The most prominent plutonics of this orogenic and magmatic revolution are the numerous granite batholiths on the Tin Islands, which in their petrographic and structural habits closely resemble the intrusive granites of the Main Range of Malaya. More basic marginal phases are in places present in smaller cupolas (S. Banca, E. Billiton, Bintan) and dikes of

granite-porphyry in granite have been observed in N.E. Billiton. Basic dike rocks and sills are known from Singkep, Banca, and Billiton. On Singkep, basic dikes have been found cutting the granite, but in N. Banca (Djeboes district) sills of diabase between radiolara-bearing siliceous shales of the sedimentary series are older than the granite, which by pneumatolytic alterations in the surrounding older rocks has been the cause of the uralitization of the pyroxenes in its basaltic fore-runners. The diabases on small islands along the northern coast of Billiton possibly are homologous to the basic sills of N. Banca.

The coarsely crystalline and porphyritic granites are the parent rocks of the primary cassiterite deposits and must have solidified at intermediate depths. The pneumatolytic and hydrothermal mineralization following upon their intrusion has developed in the roof portions of the batholiths and in the sediments outside of the intrusive contacts. A zonal arrangement of mineral associations is illustrated by the confinement of the bulk of the sulphidic cassiterite ores to the sedimentary series (Billiton) and the preponderantly "pneumatolytic" character of rock alterations within the granites (cassiterite in association with black tourmaline, topaz, white mica, quartz). The high-temperature minerals, however, spread a rather considerable distance from the granite contacts, for instance the tourmaline-cassiterite-quartz veins in slates, the pyrometasomatic silicates, magnetite and pyrrhotite of the tin lodes of Billiton (Seloemar vein, Klappa Kampit vein system, etc.). The occurrence of much hypogene magnetite, pyroxene, amphibole, garnet, biotite, and locally fayalite (Seloemar) are a characteristic feature of these stanniferous lodes in sediments.

The detrital cassiterite deposits have formed in the last stage of the process of denudation, which started after the late-Mesozoic orogeny. They are mainly of the residual type and can only partly be called strictly alluvial, although some transport of material along the bottom of the valleys must always have taken place. One can observe transitions between true valley deposits, occupying the lowest parts of the bedrock surface (the so-called

"kaksas") and residual deposits upon the valley slopes (so-called "koelits").

Weathering, chemical leaching, and mechanical transport by creep of the bottom, have played a part in concentrating the sparsely disseminated tinstone along the valley slopes and on the valley bottoms. The "kaksas" are of Holocene age and are covered by alluvial top beds of sands and clays, which in places contain true alluvial "hanging" ore beds (the so-called "mentjang" ores). The formation of the top beds has been caused by the general rising of the base level of erosion in post-Pleistocene time, when the Sunda shelf between Malaya, Sumatra, Java, and Borneo was submerged by the encroaching South China Sea. In the lower courses of the valleys, the "kaksas" commonly lie at considerable depth below sea level, up to more than 30 meters. By the formation of the top beds the process of weathering, leaching, and concentration, along the valley slopes was "frozen" up to a certain level, which formerly lay somewhat higher than at present. The last phenomenon was a slight withdrawal of the sea, perhaps over a vertical distance of 5–10 meters. The humid tropical climate has been an important factor in promoting the process of weathering. The exploitability of eluvial deposits on granitic rocks and sediments and of weathered primary deposits along granite-contacts is to be ascribed largely to this favorable climatic circumstance.

GEOLOGICAL INSTITUTE,
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MOUNT ISA ORE DEPOSITION.

ROLAND BLANCHARD AND GRAHAM HALL.

ABSTRACT.

The excellent paper by H. F. Grondijs and C. Schouten in this JOURNAL presents a study of the minerals and their occurrence in the Mount Isa ores as revealed by a microscopic study of a suite of specimens. The inferences drawn from the specimens, although logical, do not take into account the field conditions, which in certain cases alter the conclusions. The following discussion presents some of the field conditions, and detailed acquaintance with the deposits permits us to amplify some of the conclusions drawn by Grondijs and Schouten and to resolve some of the uncertainty left by their discussion.

INTRODUCTION.

THE article "A Study of the Mount Isa Ores" by H. F. Grondijs and C. Schouten, which appeared in the June–July, 1937, issue of ECONOMIC GEOLOGY, represents the outcome of careful and painstaking investigation of two suites of selected specimens from three of our mines which were sent to Professor Grondijs in response to requests of his conveyed to the London Office. The study follows upon several similar but less pretentious undertakings by other parties in previous years. As this is written, a further investigation is under way by the Queensland Geological Survey upon another suite, more comprehensive in scope, from which it is hoped to obtain information regarding the systematic, progressive changes that occur in various specific bands of ore from the surface to the lowest explored depth at approximately 1,400 feet.

The studies by Grondijs and Schouten confirm the findings of previous investigators, and add much that is new. Among the new minerals identified are pentlandite, valleriite and electrum. Penninite has been determined as the dominant chloritic mineral, and lepidocrocite has been established as a common mineral among the "limonites" in addition to the goethite previously recognized.

The article with its numerous excellent microphotographs speaks for itself, and requires no outside comment to establish the quality and high character of the work peformed.

Inferences drawn by the authors of the article are logical, and are valid insofar as the specimens constitute the evidence. Detailed acquaintance with the deposits, and with the field conditions surrounding them, permit us to amplify certain points, however, and to resolve a number of uncertainties left by the authors' discussion.

GEOLOGIC SETTING.

By way of preface it may be said that the silver-lead-zinc deposits of Mount Isa occur within certain strata of the Mount Isa shale series which comprises a two-mile thickness of thin, evenly bedded shale lying between quartzites.[1] Striking north and south, the beds dip 55–60 degrees to the west. The orebodies are localized about one-half mile from the west edge of the shale series as lenses within zones of folding and shearing. Strike and dip of the shearing conform in general, though not everywhere in detail, with that of the shale beds. Both the folding and shearing resulted from an overthrust movement from the south-southwest, the incompetent shale beds during the movement being partly rotated and doubled back upon themselves, between the more rigid quartzite retaining walls, into folded structures of intricate and complex pattern. Simultaneously, and immediately following, pressure from the thrust movement, exerted upon the steeply tilted thin shale beds, gave rise to shearing along the bedding planes, the shearing becoming especially pronounced on south limbs of the resistant folded sections of ground. The more strongly sheared areas thus became readily permeable to mineralizing solutions, and along them, on south limbs of the folded structures, without regard to whether anticlinal or synclinal pattern is involved, occur the orebodies of the district that have proved commercial to date.

[1] This paragraph is quoted largely from a brief description of the Mount Isa deposits prepared for the Committee on Processes of Ore Deposition, National Research Council.

CORRECTIONS AND AMPLIFICATIONS.

With that brief picture of the district before the reader, the following comments are offered:

1. *Slate.*—No slate occurs at Mount Isa. The country rock is a moderately consolidated shale which in many places has not progressed far beyond the "mudstone" stage, and which at no place, as far as can be ascertained from field evidence, has developed the plane surface or characteristic cleavage of slate.

2. *Intrusive Granite.*—Outcrops of granite or other intrusive do not occur near the mines. A pegmatite is present approximately two miles west-southwesterly from the orebodies. The nearest known strictly intrusive granite outcrops more than eight miles distant, though pre-ore granite-gneiss masses lie nearer. No intrusive rock has been encountered in the deepest development to a depth of more than 900 feet, or in the deepest diamond drilling to a depth of more than 1,400 feet.

3. *Shearing.*—Shearing, as the term is commonly thought of, *i.e.,* zones of fissuring and slippage that cut indiscriminately through the district, does not exist at Mount Isa. Except near faults, or in certain folded sections such as the noses of large anticlines and synclines, the shearing is confined strictly to movement along bedding planes of the shale.

4. *Primary Silver Sulphides.*—Tetrahedrite is the only primary silver sulphide specifically named by the authors. It appears to be the dominant primary silver mineral in the lower grade orebodies, such as the Black Star. In microscopic study of specimens from the higher grade ore, Professor Grondijs had previously identified polybasite ($9Ag_2S.Sb_2S_3$), pyrargyrite ($3Ag_2S.Sb_2S_3$), proustite ($3Ag_2S.As_2S_3$) and sternbergite ($Ag_2S.Fe_4S_5$). All of these, because of their position in the orebodies, must be regarded as primary.

5. *Chalcopyrite.*—On pages 426–427 Grondijs and Schouten state: "Chalcopyrite.—This mineral is found only sparingly in the lead-zinc ore, but in some parts of the deposit it dominates, where lead and zinc are less conspicuous. . . . As far as can be judged from the samples examined, it seems that in general chalco-

pyrite is accompanied by carbonates, whereas pyrrhotite is generally found in quartz gangue."

The chalcopyrite referred to lies outside the silver-lead-zinc orebodies, in the Black Star hangingwall, where, along the particular line of section referred to (North co-ordinate 6422) the shale has been almost wholly replaced by coarsely crystalline dolomite and ankerite in thicknesses ranging from 20 feet at 400-foot depth beneath the surface to 200 feet at 1200-foot depth beneath the surface. Most of the district's chalcopyrite, which occurs in amounts readily distinguishable to the unaided eye, lies outside the silver-lead-zinc bodies, mainly in the coarsely crystalline dolomite areas. Small amounts of it (mostly only microscopic quantities) exist within the orebodies, in places as fracture fillings that cross the shale, pyrite, sphalerite, carbonate, and quartz, showing it to have been one of the later minerals, in other places as replacements of the pyrrhotite and sphalerite.[2]

6. *Age of Folding.*—In several places the statements of Grondijs and Schouten convey the impression that much of the folding may have occurred subsequent to deposition of the ore minerals, although that fact is not specifically stated except on page 409, where they say, "In places the sphalerite-galena-carbonate layers are microscopically strongly folded, whereas the adjoining pyrite-slate layers are entirely undisturbed."

Mount Isa's highest grade silver-lead-zinc ore, for any given mine or portion thereof, occurs in the sections of ground that are most highly crenulated by small folds (Fig. 2). The ratio of Ag to Pb is notably higher (generally 50 per cent or more), and that of Zn to Pb notably lower, in such portions than elsewhere. Except for a few isolated, slightly curved galena surfaces, we have observed little microscopic evidence of folding subsequent to deposition of the ore, nor have we recognized in microscope work at the mine, or in microphotographs made by others, clearly defined evidence thereof. Such evidence as we have is far more persuasive that, except in rare instances on a very minute scale, the thin shale beds not already replaced by the fine grained pyrite

[2] In this paper the term "sphalerite" denotes the zinc sulphide at Mount Isa, which carries .075 per cent isomorphous Fe for each 1 per cent of Zn present.

became minutely crenulated before and to some extent in conjunction with the main shearing movement, and the ore minerals selectively replaced them following such crenulation and shearing. Field evidence is convincing that essentially all folding and faulting had been completed before deposition of the ore minerals took place, even though the third deformational (a minor crushing) movement discussed below, occurred after ore deposition was well advanced but had not terminated. In addition to the visual evidence adduced to show deposition of the ore subsequent to crenulation and folding, is the fact consistently disclosed by analyses that the Ag to Pb ratio is substantially higher, and the Zn to Pb ratio substantially lower, in the crenulated areas than elsewhere in a given mine. Such would not be the case had the folding occurred subsequent to ore deposition.

Not only were virtually all of the silver-lead-zinc sulphides deposited subsequent to folding and crenulation of the shale beds, but the synclinal portions of the folded and crenulated ground carry as high a silver-lead content per cubic volume, and as favorable an Ag to Pb ratio, as do the anticlinal portions. This fact was first noted by R. P. Hooper in the early Mount Isa prospecting days. It yields food for thought to the enthusiasts who indulge in sweeping generalizations about ore deposition along anticlinal structures as opposed to synclinal ones.

7. *Graphite.*—On pages 429–430 Grondijs and Schouten state, "Graphite is generally taken to be formed at rather high temperature or pressure, in pegmatitic-pneumatolytic ores or in contact metamorphic deposits. The presence of graphite in the Mount Isa ore is therefore of interest, not only because it has probably been formed at no high temperature, but also because here it occurs in a form, which until now, we believe has not been described. . . . Its rare occurrence and the small dimensions of its grains make any conclusion as to its origin difficult."

We concur in their conclusion that no satisfactory explanation for the graphite rings, or "radial-fibrous shells," which in isolated instances occur within the Mount Isa orebodies, is at hand.

As to carbon content of the ore, it may be said that most of the

Mount Isa shale beds that have been tested yield readily determinable amounts of fixed C; that the amounts have been as high as 1.89 per cent fixed C and more than 4 per cent volatile hydrocarbons; and as high as 4.2 per cent fixed C in similar pre-Cambrian shale not far from the Mount Isa deposits. Likewise, in numerous specimens analyzed, the shale beds a mile or more from the orebodies yield as high carbon content as do those within the ore areas.

Although the age of the Mount Isa shale series is not established, there is general agreement that it is late Middle, or early Late, Proterozoic. In the Adelaide series of South Australia, which is Late Proterozoic, David and Tillyard [3] have found giant Annelids up to 18 inches long and 2 inches wide, and giant Arthropods up to 15 inches long by 3 to 4 inches wide and 10 inches across from tip to tip of their large appendages. In the Mount Isa shale series they have found smaller Annelids.[4] A definite fossil impression, which was found centrally within the main orebody upon No. 1 level of the Black Star mine at Mount Isa, has been identified by Tillyard [5] as probably closely related to the Characeae. It consequently is difficult to escape the conclusion that organic life flourished at least in moderation at the time the Mount Isa shale series was being laid down.

Although the shale series is enclosed on both sides of its two-mile thickness by pre-Cambrian quartzite, hornblende schist, gneiss, and other rocks which have been subjected to and strongly deformed by regional metamorphism, the shale series itself exhibits none of those effects except for the local folding and fracturing previously referred to. The shale is only moderately consolidated, and has the appearance of shale beds of relatively recent deposition. Probably in no environment would early pre-Cambrian organic life have had a better chance for fossil preservation than in the Mount Isa shale series.

[3] David, T. W. E., and Tillyard, R. J.: Memoir on fossils of the late pre-Cambrian from the Adelaide Series of South Australia.

[4] David, T. W. E.: Explanatory notes to accompany a new (1932) geological map of the Commonwealth of Australia, p. 32.

[5] Tillyard, R. J.: Private communication to R. B., August 25, 1936.

Whether the graphite rings, or "radial-fibrous shells," found in the Mount Isa ore constitute graphite imperfect pseudomorphs after pre-Cambrian fossils, through recrystallization from the abundant carbonaceous matter within the shale, whether they constitute a hitherto unrecognized form of inorganic deposition associated with the pegmatite intrusion two miles distant, or whether some other explanation accounts for their existence, are matters upon which we hold no opinion. The facts of organic life as we know them are set forth, along with the other factors, merely for the reader's consideration.

8. *Syngenetic Origin of the Fine Grained Pyrite.*—On page 409 Grondijs and Schouten state, "Stratification of the ore minerals is so perfect, down to the minutest detail, that one's first conclusion is of a syngenetic origin."

The evidences of metasomatic replacement of the shale as furnished by microphotographs in the article, are so numerous at the mines macroscopically, that probably no observer at the property would consider seriously a syngenetic origin. Were further proof required, it would consist in:

(*a*) The Mount Isa series comprises a group of exceptionally thin shale beds that maintain their continuity and physical characteristics over long distances. A three-inch section of beds, which individually range from $\frac{1}{50}$ to $\frac{1}{100}$ inch in thickness, normally has its various strata as strongly defined a mile or two from the orebody as within (unmineralized) portions of the orebody itself. In the entire two-mile thickness of the series, no bed exceeds 1 foot, and few exceed ½ inch, in thickness. We know of no other shale deposit in which such persistence of very thin beds is so consistently maintained in uniform thickness over distances of many miles.

(*b*) Had the fine grained pyrite been laid down syngenetically with such beds, and under such necessarily quiet and uniform conditions of deposition, it would need to show, likewise, consistent continuity along the beds over long distances.

(*c*) It does not show such continuity. Its deposition is sharply limited to the sheared or otherwise deformed sections of

shale in the vicinity of the orebodies. Although it may persist for a mile along the strike beyond the orebodies in a particular group of well sheared beds, in most of the beds it dies out along their strike within a few hundred feet of the orebodies, and has been found in numerous instances to die out similarly at a few hundred feet or less down the dip beneath the smaller orebodies where exploratory work has exposed the condition. Except for its occasional further persistence along a particular group of well sheared beds as noted, the fine grained pyrite at Mount Isa constitutes in a general way an aureole about the orebodies, much as the sericitized rock constitutes an aureole about many of the disseminated porphyry copper deposits of southwestern United States.

9. *Deformation and Mineralization.*—On page 409 Grondijs and Schouten state, " Prior to and during mineralization the slate country rock has been sheared, broken, folded, faulted and in places finely crushed. . . . Fault movement as a rule does not exceed a couple of millimeters. . . . The different layers of mineralized country rock may behave differently; whereas layers consisting mainly of slate and pyrite are traversed by clean breaks and faults, the adjoining layers with sphalerite, galena, carbonate and quartz may have suffered only slight folding."

Some of these matters have been dealt with above. A brief review of the district's deformational history may assist, however, in clarifying the picture as a unified whole.

STRUCTURAL FEATURES.

Three distinct deformational movements are recognized, all belonging to one general period of overlapping effects:

A. The first, or major overthrust movement, which brought about principal contortion of the shale, most of the folding, and the larger part of the faulting. During this movement there were expressed, within the shale, folds with horizontal " throws " of more than 600 feet, and faults with vertical displacements ranging from several hundred to a thousand feet. The movement is responsible for the formation of the breccia zones, which

consist of broad bands up to a hundred or more feet wide of thoroughly crushed shale striking nearly parallel to the bedding but dipping several degrees more steeply, and paralleling closely on either hanging or footwall the present orebodies but not embracing them. Toward the end of the major deformational movement, the breccia zones became strongly impregnated with silica, and to a lesser degree with fine grained pyrite. The breccias, with their cavernous, siliceous bodies resulting from weathering away of the more soluble constituents, constitute the resistant portions of the landscape today. They are topographically impressive, but carry little or no ore.

B. The second, crushing and shearing movement, with which was associated deposition of most of the fine grained sulphides of all types. Pressure from the overthrust movement did not subside abruptly. It continued in moderated form, causing extensive crushing and fracturing of the silicified breccia masses, together with internal dislocations thereof, especially along their strike. The breccias thereupon became impregnated with and in part replaced by carbonate minerals, mainly medium to coarsely crystalline dolomite and lesser ankerite, which formed a stockwork that is plainly visible in many places underground within the sulphide zone today.

That the deposition of the carbonate followed deposition of the first fine grained pyrite is evidenced by the fact that dolomite of the stockwork in places encloses small, plucked islands of the pyrite.

Coincident with the crushing movement, the adjacent, softer shale beds underwent extensive shearing, mainly along their bedding planes. Some shearing and deposition of fine grained pyrite almost certainly had taken place within those beds during the first deformational movement, but the virtual freedom of such areas from invasion of the silica that had been so copiously deposited in the adjoining breccias, argues against important shearing or fracturing of the ore-bearing areas during the first movement. It seems more likely that the breccia masses, like the resistant, larger folded sections of ground, offered firm op-

position to this gentler crushing movement, resulting in slipping and shearing of the unsilicified thin shales along their bedding planes. Before the second crushing movement had subsided but obviously during its later stages, occurred general impregnation of the more strongly sheared areas by pyrite,—most of the fine grained "spherical," idiomorphic and idioblastic, and skeleton-shaped pyrite designated as (*a*), (*b*), and (*c*) by Grondijs and Schouten presumably occurring at this time. With few exceptions deposition of the fine grained pyrite began as interbed replacements along the sheared bedding planes, thereafter progressively advancing their front into the body of the shale layers on either side.

Closely related in point of time to the deposition of the fine grained pyrite was a second invasion of silica. It was of spotty distribution within the sheared areas, largely confined to selective replacement of specific shale beds, and generally so imperfect as not to be readily distinguishable to the unaided eye from the unsilicified beds except as dimly defined "ribbonstone." In many instances it replaced imperfectly the shale interstices between the fine grains of pyrite, and in part, at least, therefore must have followed the deposition of the latter. In extent and replacement power it is quite insignificant compared with the silica invasion of the breccias during the first movement, but is relatively more important in a microscope study of the ores because of expressing itself largely within the areas that contain the orebodies.

Toward the close of the main period of fine grained pyrite, and of the second silica deposition, after the second crushing movement had largely subsided and essential quiescence reigned, occurred introduction of most of the ore sulphides. Immediately preceding and throughout that period further carbonate, still mainly dolomite and ankerite, was deposited. It became more pronounced toward the end of the period. Evidence for this is the concentration of carbonate within the sheared areas mainly around peripheries of the orebodies. Since shale marker beds, which within the orebodies remain consistently unreplaced by sulphides (Figs. 1 and 2), commonly are dolomitized at the ore-

FIG. 1. Fold in No. 2 stope of the Black Rock mine. The broad bands are unreplaced shale. Interbed replacement along sheared bedding planes is well illustrated, with replacement not having penetrated into the beds importantly. Note in lower right hand corner that the ore bands occupy spaces replaced subsequent to the folding and faulting (second crushing movement), and that the open fracturing of the broad shale band represents a (third) crushing movement later than the ore, with virtually no displacement. No ore was deposited along the later fractures in this instance.

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FIG. 2. Crenulated section of the O'Doherty lode, Black-Rock mine. Here the ore not only has invaded the shales along their bedding planes, but has penetrated and almost completely replaced the thinner shale members, and has filled numerous fractures within the broader folded, otherwise unmineralized, shale bands. The replacement clearly took place subsequent to the folding and principal fracturing. Were further evidence needed to establish that point, it would be found in the fact that within the crenulated and strongly folded sections of ground the Ag to Pb ratio is consistently higher, and the Zn to Pb ratio consistently lower, than in uncrenulated sections of the same mine. Two open cracks in upper center of the picture are post-mine fractures. Note that the synclinal folds are mineralized equally with the anticlinal ones.

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bodies' peripheries, but are not dolomitized within the main portions of the orebodies themselves, it cannot be argued that in general the beds now containing the oreshoots had been replaced by extensive carbonate minerals, and subsequently replaced by sulphides, even though numerous instances may be found of the ore minerals replacing the carbonate. Further evidence of late deposition of much of the carbonate is the fact of its code position with chalcopyrite in the strongly dolomitized areas, and the fact that chalcopyrite, as already noted, is one of the later minerals of the second deformational-mineralization period.

That faulting as the term is thought of by the mine operator, *i.e.*, recognizable displacement of at least several inches, had virtually ceased before the second movement was well under way, is evidenced by the fact that in almost every instance within the ore areas, the grade of ore diminishes within several to as much as forty feet from the faults, due to fact that the shale beds adjoining the faults (as was also the case with the breccias) had been rendered partly or wholly immune to mineralization by the ore sulphides through previous strong impregnation with silica. The minor faulting referred to by Grondijs and Schouten as, " fault movement as a rule does not exceed a couple of millimeters," must have occurred, however, during this period—subsequent to the deposition of the fine-grained pyrite but before important deposition of the ore sulphides.

That shearing along the bedding planes within the orebearing areas, or at least reopening of pre-existing mineral courses along bedding planes, likewise continued throughout the second period, is attested by the fact that during this main ore deposition period, the silver-lead-zinc solutions consistently penetrated along bedding planes to replace the previously deposited fine-grained pyrite (and pyrrhotite) there and upon either side. The condition is much more obvious to the unaided eye of a person passing through the stopes and viewing the bands of galena-sphalerite encroaching upon the adjoining pyrite bands in the center of the ore-shoot but gradually tapering out to thin seams or completely losing their identity within the pyrite as the ends of the ore-shoots are ap-

proached, than it may be to the microscopist viewing only the restricted portions of a given sulphide band in an individual specimen or group of them.

C. The third, cross fracturing movement. Subsequent to deposition of the main body of ore sulphides occurred a third deformational movement. In some places it resulted in the reopening of old faults without appreciable displacement, and the injection of " spurts " of silica, coarse calcite, and ankerite along them. On the whole it consisted merely of gentle crushing of the solidified orebodies and the enclosing rock. Its gentle character is illustrated in Figs. 1 and 2, and by the fact that it took place almost wholly in areas of pre-existing weakness, such as in vicinity of faults, major folds, or noses of large anticlines or synclines. Elsewhere the orebodies and rock are little affected. Except for the reopening of former faults—mostly those of northeast-southwest trend as opposed to those of northwest-southeast trend—the movement expressed itself in local shattering of both the rock and the orebodies, more or less as vertical fractures at right angles to the strike of the beds. It expressed itself to a much lesser degree along the strike of the beds and orebodies as fractures of nearly horizontal dip. These, likewise, occur mainly in the immediate vicinity of pre-existing faults.

The combined conditions suggest that locus of the third movement lay southwestward or westward from the orebodies, rather than south-southwestward as had that of the first and second movements, and that the locus of the third movement lay at a higher elevation than had that of the other two.

Since the only vein quartz and coarse calcite known in the vicinity of the mine was injected at this time; since both, particularly the quartz, outcrops increasingly through the country rock to the west and southwest as the pegmatite is approached; and since the pegmatite outcrops mainly to the west-southwest of the mines from which direction the third deformational movement came; there seems evidence, though not specific proof, that injection of the pegmatite into that area was responsible for the third, minor, deformational movement.

The cross-fractures of the third movement transect all of the fine grained sulphides of the orebodies in the portions affected. Along those cross-fractures, and almost invariably also within the " spurts " of quartz and calcite injected along reopened faults, have been deposited most of the coarse sulphides, particularly the galena and pyrite noted by Grondijs and Schouten.

Deposition of the coarse sulphides, particularly galena, occurs also along the strike of the beds in more or less homogeneous bands, up to several inches wide, along various short stretches within the high grade orebodies, as at the Rio Grande mine. The high grade orebodies occur exclusively in areas of highly folded and faulted ground; suggesting that shearing or reopening of beds along their strike within the orebodies occurred during the third movement mainly or solely in very weak sections of ground; and that such reopening, with admission of the coarse galena, is chiefly responsible for the added richness of such areas in contrast with the lower grade, unaffected, or less affected areas represented by the Black Star orebodies.

Although the coarse sulphides, particularly the galena, are impressive within the stopes, we estimate that they constitute probably not much more than 5 per cent of the total ore sulphides deposited in the district.

Mineralizing Intrusives.—Close relationship of the third deformational movement and injection of coarse sulphides, with the pegmatite, together with the nature of the earlier deformational movements, suggests that the first and second movements, and deposition of the fine grained sulphides of all types, are related to a magma that invaded and exerted its pressure from a point well beneath the existing surface, lying south-southwesterly from the present positions of the orebodies. Southward persistence with depth of the sheared " lenses," and strong southward rake of all oreshoots except where local structure caused deviation therefrom, are in agreement with that supposition. Later injection of the pegmatite at a point farther northward and more westerly from the orebodies, but likewise nearer the weakened area into which the main bodies or ore minerals had been

injected, and at a higher elevation corresponding closely with the present surface, together with deposition of the coarse sulphides, would seem to represent the final exertion of the magmatic invasion with which had been accompanied the deformation and mineralization of the district.

A large body of intrusive granite, unmapped but known to be many miles in diameter, lies westerly and southwesterly from Mount Isa at distances upward of 8 or more miles, though it does not outcrop at the point from which the overthrusting and crushing of the first and second deformational movements must have originated.

More evidence is needed before deformation and mineralization of the Mount Isa district may be related with confidence to the granite and the pegmatite as above suggested, but the hypothesis conforms with all facts known at this time regarding the deposits.

MOUNT ISA MINES LIMITED,
MOUNT ISA, QUEENSLAND,
October 15, 1937.

DISCUSSION AND COMMUNICATIONS

PARAGENESIS OF PYRRHOTITE

Sir: In his paper "The Paragenesis of Pyrrhotite" (this Journal, vol. 32, pp. 31–55, 1937), G. M. Schwartz enumerates many of the associations in which pyrrhotite is commonly found. There are some others, however, of which no mention is made, and one, in particular, which, though given passing reference among the list of "Other Minerals" (p. 51), seems worthy of more attention. This last refers to the occurrence of pyrrhotite with molybdenite, which is rather casually dismissed as an "occasional" association.

Molybdenite is a common mineral in the Grenville series of eastern Ontario and southwestern Quebec, where it is found as flakes, sometimes of large size, in pyroxenite bodies. Pyrrhotite is a very common associate of such molybdenite, and is, indeed, regarded as a significant mineral, heavy pyrrhotite mineralization being held to be a favorable "indicator" for molybdenite. The prevalence of pyrrhotite in many of the Ontario and Quebec molybdenite occurrences has already been recorded.[1] Although its presence in places is masked by more abundant pyrite (also a typical associated sulphide), it is probable that careful search would reveal the presence of pyrrhotite in most of the deposits. I do not know that any systematic study has been made of the paragenesis of the two iron sulphides in such association, but it would seem reasonable to suppose that pyrrhotite was the earlier mineral to form. It is reasonably certain that the molybdenite was not a primary mineral of the pyroxenite bodies (basic pegmatites), but was introduced into them along fractures and solution channels through the agency of heated solutions emanating

[1] Molybdenum. Can. Dept. of Mines, Mines Branch, Rept. no. 592, 1925.

from nearby bodies of granite pegmatite. Such acid pegmatite may underlie the pyroxenites, at depth, or, in some cases, actually inject them in dike form or as irregular schlieren. Pyroxenite seems to serve (in the case of the Eastern Canadian deposits), as an extremely favorable host rock for molybdenite, and most of the occurrences are found in it. It is not uncommon, also, to find small pockety masses of molybdenite in the Quebec and Ontario pyroxenitic phlogopite-apatite deposits, where such are cut by acid pegmatites, the molybdenite, in such case, being invariably in the pyroxenite, adjacent to the intrusive, and not in the latter. A paragenetic study of the molybdenite-pyrrhotite-pyrite association in the molybdenite occurrences of the above district should be of interest. Molybdenite is a fairly high-temperature mineral, and it would seem reasonable to expect that the pyrrhotite (also a high-temperature mineral) accompanied its deposition. Just where the pyrite comes in the succession, and whether it replaces pyrrhotite, or vice versa, is a moot point.

In many of the pyroxenitic phlogopite-apatite deposits of the same region, pyrrhotite is a common mineral, and is probably even more abundant than pyrite, which is rarely absent. I have already mentioned [2] this association.

In highly-metamorphosed zones of the Grenville crystalline limestone, in Ontario and Quebec, where the rock is cut or injected by acid pegmatite, pyrrhotite is conspicuous among the large variety of introduced minerals. It is generally present as small anhedral grains, which often exhibit pitted or resorbed surfaces, and is far more common than pyrite in such rock. On lot 23, concession XIII of Monteagle township, Hastings county, Ontario a deposit of flake graphite in such a silicated zone in crystalline limestone was formerly worked. Pyrrhotite, in large, thin, platey crystals, was noted in vugs in the ore.[3]

In the township of Joly, range I, lot 16, Labelle district, Quebec, heavy pyrrhotite mineralization is associated with mas-

[2] Mica, its occurrence, exploitation and uses. Can. Dept. of Mines, Mines Branch, Rept. no. 118, p. 295, 1912; also Phosphate in Canada, Rept. no. 396, p. 137, 1920.

[3] Graphite. Can. Dept. of Mines, Mines Branch, Rept. no. 511, p. 28, 1920.

sive almandite garnet in veins consisting essentially of these two minerals, cutting biotite garnet gneiss.[4]

A further occurrence of pyrrhotite that deserves mention is that in certain of the granite pegmatites of Ontario and Quebec. Dr. Schwartz writes me (June 19th, 1937) that pyrrhotite was not noted in any of the pegmatitic material that he examined, and I am inclined to think that it must be rare in American pegmatites. It is not exactly common in Canadian pegmatites, which generally carry pyrite as the dominant sulphide mineral, but is in places met with in considerable amount. The Macdonald feldspar mine, in Monteagle township, Ontario, near Hybla, has yielded large masses of pyrrhotite, which occurred associated with a mass of pink calcite encountered in one section of the workings; a variety of minerals accompany the pyrrhotite, notably quartz, cyrtolite, titanite, and such rare-element minerals as ellsworthite, uranothorite and hatchettolite. In more disseminated form, pyrrhotite also occurs plentifully in the pegmatite worked on the adjoining Sutherland property. A narrow pegmatite dike, worked in a small way for feldspar, on lot 11, range I, of Derry township, Papineau county, Quebec, yielded several hundred pounds of massive pyrrhotite. The mineral also occurs plentifully, in both massive and disseminated form, in a pegmatite dike that cuts crystalline limestone in range III of the Augmentation of Grenville, Que., and in small embedded grains in the feldspar, diopside, calcite, etc. of a similar pegmatite in concession V of North Burgess township, Ont.[5]

In a rather unusual type of phlogopite mica deposit in Bedford township, Frontenac county, near Godfrey, abundant massive pyrrhotite, associated with pyrite, occurs. The mica lead appears to follow a rather persistent fracture zone in white crystalline limestone, and the mica is apparently of metamorphic origin, formed by ascending pneumatolytic solutions from an underlying

[4] Abrasives. Can. Dept. of Mines, Mines Branch, Rept. no. 677, Pt. 3, Garnet, p. 21, 1927.

[5] See also Can. Dept. of Mines, Mines Branch reports no. 731, "Feldspar," p. 72, 1932, and no. 401, "Feldspar in Canada," p. 21, 1916, as well as my paper "Pegmatite Minerals of Ontario and Quebec," Amer. Miner., vol. 15, pp. 450, 487, 1930.

acid intrusive. Individual mica crystals are often seen embedded in solid pyrrhotite. Tremolite and brown tourmaline are the other dominant minerals.

Pyrrhotite, indeed, seems particularly abundant in pegmatites enclosed in the Grenville limestones and might even be said to be characteristic of such deposits. It is noteworthy that the entire mineral assemblage of such bodies, including the feldspar itself, as well as the secondary calcite and silicates, such as diopside, mica, scapolite, etc., is invariably characterized by a strongly foetid odour due to occluded H_2S. This would indicate an excess of sulphur in the pneumatolytic solutions, over and above that required to satisfy the iron present, and this raises the question why pyrrhotite should have been formed in preference to pyrite. The reason can hardly be attributable simply to high temperature conditions, since, as in the case of the Bedford mica deposit just mentioned, both pyrite and pyrrhotite are occasionally found intimately associated in such deposits. It seems probable, also, that the source of the sulphur was the intruded limestone, rather than the pegmatite magma itself.

I am aware that Dr. Schwartz, in his paper, was dealing with pyrrhotite in its specific relation to metallic ores, but the above notes on the occurrence of the mineral in other and additional association may serve to amplify what he has recorded.

HUGH S. SPENCE.

BUREAU OF MINES,
OTTAWA, ONT.,
July 22, 1937.

THE ORIGIN OF PRIMARY LEAD ORES.

Sir: Professor Arthur Holmes' stimulating paper on the Origin of Primary Lead Ores (this JOURNAL, vol. 32, pp. 764–782, 1937) challenges one of the most widely accepted theories of ore genesis. He holds that "the proof is complete that ore-lead can not be a concentration from either granitic or basaltic rocks, or from their respective magmas."

Atomic weight determinations are of such precision [1] that we can accept the fact that all ore leads regardless of the geologic time of their origin have the constant atomic weight of 207.21. This constancy, it can be agreed, proves that at least some ore-leads were not formed "by any process of lateral secretion."

For example, the lead in an old Pre-Cambrian granite might be extracted by a process of lateral secretion and deposited to form ore, say in late Mesozoic time. During the postulated long interval (between the Pre-Cambrian and the late Mesozoic) the original lead content of the granite would be augmented by radiogenic lead derived from the uranium and thorium content of the granite; and as Dr. Holmes has shown, the Pb^{206} content of this radiogenic lead would probably predominate over the thorium-derived lead (Pb^{208}), with the result that the ore-lead formed in late Mesozoic time would have an atomic weight less than 207.21; which decrease, if more than a few units in the second decimal, could certainly be detected by the chemist or physicist.

The qualification, "at least some lead ores," is necessary, because if the lead ore of any particular metallogenic epoch were deposited by meteoric waters that had extracted their lead from a solidified cooling igneous mass, which is itself the ore-bringer, then the atomic weight of the lead in the ore would of course be the same as the atomic weight of the lead in the granite. As shown later in this discussion, the atomic weight of this lead would depend on whether the granite magma had been derived by "primordial" differentiation early in the history of the globe or had originated much later during the metallogenic epoch.

The constant atomic weight of ore-leads regardless of geologic provenance appears furthermore to prove that no lead ore bodies

[1] Lead extracted from Katanga pitchblende was prepared in duplicate samples at Cambridge, Mass. One was retained at Harvard for atomic-weight determination and the other sent to Munich. By agreement between Professor Baxter and Professor Hönigschmidt, the results of the determinations were mailed on the same day from Cambridge and Munich, respectively. The letters crossed in mid-Atlantic; when opened they showed Katanga lead has an atomic weight 206.027 (Baxter and Alter) and 206.030 (Hönigschmidt). Cf. Baxter, G. P., and Alter, C. M.: The atomic weights of several radiogenic leads. American Chem. Soc., Jour., vol. 57, p. 469, 1935.

have been formed by magmatic emanations given off by palingenic granites (if there are any such!). For, if between the original emplacement of the granite and its subsequent remelting *i.e.* date of palingenesis, sufficient time, say several hundred million years, had elapsed, the lead formed during the interval by the radioactive disintegration of the uranium and thorium content of the granite might cause an appreciable diminution of the atomic weight of the total lead present.[2]

The main conclusion of Dr. Holmes that lead ore bodies cannot have originated from emanations from primary granite magmas does not appear to be cogently proved. Throughout geologic time, as the geologic evidence clearly shows, there has been an abundant source of basaltic magma. The probability is rather strong that in any petrogenic epoch, from the earliest Pre-Cambrian to the present, the various magmas were differentiated from basaltic magma, which was formed *de novo* instead of by primordial differentiation [3] in the beginning of geologic time. In terms of the problem here discussed, the ore-bringing magma of of each metallogenic epoch was derived *de novo* from a basaltic magma, which itself was newly derived early in the petrogenic epoch from more basic material. This basic material was the result of selective fusion of deep-seated peridotite analogous in composition to meteoritic material.[4] This source material is relatively rich in ordinary lead [5] and is so poor in radioactive matter that despite the great age of the Earth, the minute amount of radiogenic lead formed and added to the lead primordially present has been insufficient to cause any appreciable deviation from the normal atomic weight 207.21. The source material has been

[2] One of the criteria suggested for the recognition of palingenic granites is that such masses are sterile of ore deposits. (Eskola, Pentti: On the origin of granitic magmas. Min. Petrograph. Mitt., Bd. 42, p. 478, 1932.) That the atomic weight of all ore-leads formed throughout geologic time is $207.21 \pm .01$ can be regarded as confirming the belief that palingenic granites are in fact sterile, or on the other hand as indicating that there have been no palingenic granites.

[3] Bowen, N. L.: The evolution of the igneous rocks, pp. 319–320, 1928.

[4] Bowen, N. L.: Op. cit., pp. 311–320.

[5] Some quantitative evidence bearing on this point is given by G. von Hevesy (Die geochemische und kosmische Häufigkeit des Bleis. Fortschr. Min. Krist., Petrog., Bd. 16, pp. 147–161, 1932).

tapped during successive petrogenic epochs from the earliest Pre-Cambrian onward by the generation *de novo* of basaltic magma, but the atomic weight of the lead entrained remained essentially 207.21. During the course of each petrogenic epoch the lead, thorium, and uranium, in accordance with the laws of magmatic differentiation, became concentrated in the granitic fraction,[6] but the length of time of any of these petrogenic cycles was far too short for the lead radiogenically formed during any of them to have an appreciable effect on the atomic weight of the lead. Therefore, the ore-lead deposited from the emanations given off by a magma that had thus been currently generated from a deeper source of basic material would have the normal atomic weight of ordinary lead (207.21). This hypothesis reconciles Dr. Holmes' conclusion that ore-lead "must have ascended from depths below the sialic and basaltic layers of the lithosphere" with that of the widely accepted idea of the genetic dependence of lead ores on granite magmas.

The problem of the atomic weight of ore-lead, it would appear, is intimately connected with the fundamental problem of the origin of magmas. The evidence from the constant atomic weight of ore-lead can be considered as support from an unexpected source for the theory of the derivation of granitic magmas by differentiation from basaltic magma and the origin of the parental basaltic magma by selective fusion of deep-seated peridotite analogous to meteoritic material.

ADOLPH KNOPF.

YALE UNIVERSITY,
Nov. 10, 1937.

[6] All the analyses of radioactive content of rocks so far made have been assembled by H. Jeffreys and statistically evaluated. They show "that in general the order dunite, plateau basalt, basalt, granite is one of increasing mean radioactivity and also of increasing variability of the radioactivity in comparison with the mean" (Jeffreys, H.: On the radioactivities of rocks. Gerlands Beiträge zur Geophysik, Bd. 47, p. 166, 1936).

REVIEWS

The First Hundred Years of the Geological Survey of Great Britain. By Sir J. S. Flett. Pp. 280, pl. 13. His Majesty's Stationery Office. London, 1937. Price $2.15.

The occasion of this interesting outline of the history of the oldest government geological survey was the celebration of its centenary and of the opening of the new home of its protégé, the Museum of Practical Geology at South Kensington.

The book not only covers the history of the activities of the British Survey but it also describes the evolution of the knowledge of the geology of Great Britain and shows through whom the advance of this knowledge was made. There are many short sketches of the men, connected with the Survey, whose names are familiar to all geologists, and brief statements of the contributions they have made to the advance. Since about 300 names of members of the staff of the Survey and the Museum are listed with their biographical data, the list is a convenient directory of the active geologists of Britain during the past century. Incidentally, it records the birth and separation from it of its daughter institutions, the Royal School of Mines, the Mining Record Office, and the Museum of Practical Geology.

The volume is illustrated with photographs of the seven Directors of the Survey and of twelve other well-known members of its staff. The book contains an immense amount of information on the geology of Great Britain and of the steps by means of which this information was obtained.

W. S. Bayley.

Petrology of the Volcanic Area of Bufumbira. By Arthur Holmes and H. F. Harwood. Pp. 300; figs. 8, pl. 5; map. Geol. Survey of Uganda. Entebbe, 1937. Price 21/.

This is an authoritative, detailed, petrographic study of an unusually interesting series of recent volcanic rocks erupted near the Rift valleys, accompanied by 26 new chemical analyses by Dr. Harwood. Several new varieties are described. The mode of origin is discussed and comparisons are made with related rocks of other lands.

A scholarly chapter on Petrogenesis presents discussions of the origin of these rocks, their relationship to other basic igneous rocks, and the

"Role of Ultrabasic Rocks, Magmas, and Emanations." Various hypotheses of differentiation are discussed and superseded by a theory of transfusion by "Flux of Emanations" which is resurrected from obscurity and critically analyzed and added to. The conclusions are of interest to economic geologists in connection with ore genesis.

The mode of differentiation suggested and a study of recent gravity anomalies by Dr. Bullard, lead Professor Holmes to support Dr. Wayland in advocating horizontal compression instead of tension in forming the Rift Valleys.

Dr. Wayland and the Uganda Survey are to be congratulated in having to their credit so excellent a work by such distinguished authors as Professor Holmes and Dr. Harwood.

ALAN BATEMAN.

Die Metallischen Rohstoffe, ihr Lagerungsverhältnisse und ihre wirtschaftliche Bedeutung. 1 Heft. Vanadium, Uran, Radium. By Dr. P. KRUSCH. Pp. viii + 148. Fig. 17. F. Enke, Stuttgart, 1937. Price 10 R.M.

This is the first of a series of 15 proposed brochures, dealing with the occurrences, preparation and uses of the ores of the metals.

After listing the minerals containing the metal named in its title all their deposits throughout the world are described, their geological environment outlined and the theories of their origin summarized. Then follow a condensed statement of the methods employed in transforming the ore into merchantable compounds and the uses of the products.

There is very little that is new in the booklet, but, on the other hand, it contains a great deal of information that is difficult of access to most geologists, since much of it is scattered through publications that are not available in most libraries. The author has evidently combed the literature for his material and has done it well. The sections on the radioactivity and helium content of the German salt deposits and on the radium content of spring and well-waters are particularly interesting because they bring together in one place the widely-spread information on the subjects.

W. S. BAYLEY.

Mineral Raw Materials. By the Staff of Foreign Minerals Division, U. S. Bureau of Mines. Pp. 342; figs.; tables. McGraw-Hill Book Co., New York, 1937. Price $5.00.

This study indicates present supplies and the interdependence of nations for needed raw materials. This information is more necessary since many countries of late have restricted imports and exports.

Part I covers the 32 most important industrial materials. For each, there is given a list of minerals, modes of occurrence, the principal deposits of the world, industrial uses, production, and world trade charts. Part II is a survey by countries in which is included, administration, production summary distribution, developments since 1929, and tables of imports. The volume contains a wealth of information relating to mineral economics and should prove a handy reference to geologists and engineers.

The Mines Register, 1937. JOSEPH ZIMMERMAN, Editor-in-chief. Vol. XIX. Pp. 1340 + 282 pp., index, etc. Atlas Publishing Co., Lafayette St., New York, 1937. Price $25.00.

Those who desire to look up information regarding North American and foreign mining companies have awaited with interest and impatience the appearance of this volume. It is a worthy successor to the Mines Handbook, whose last appearance was in 1931, and to its predecessor, the Copper Handbook, first published in 1900.

This volume of specially condensed type contains descriptions of 7,500 mines in North and South America and also other important foreign mining companies. It indexes inactive mines, and has a handy section on metal statistics and price ranges of major companies. There is a good glossary of mining terms, a section on mineralogy of ore minerals, a long list of mining officers and directors, one of mining engineers, a directory of mine equipment, and lists of smelters and assay offices. It is useful, handy, comprehensive, and authoritative, and should be available to all companies, publishers, and individuals who desire information regarding mines.

BOOKS RECEIVED.

J. D. BATEMAN.

Preliminary Geologic Map, State of Washington. Edited by G. W. STOSE. Scale 1 in. = 8 miles, 32 × 52 in. Division of Geology, Pullman, Washington, 1936.

Reconnaissance and Elevation Map of S. E. New Mexico. W. B. LANG. Scale 1 : 190,080. 35 × 60 in. Socorro, New Mexico, 1936.

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Oil and Gas Map of New Mexico. D. E. WINCHESTER AND A. ANDREAS. 16 miles to the inch. 24 × 26 in. State Bur. Mines and Mineral Resources, Socorro, New Mexico, 1936.

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SOCIETY OF ECONOMIC GEOLOGISTS

Abstracts of papers presented at the Eighteenth Annual Meeting, in conjunction with the Geological Society of America, Washington, D. C., Dec. 28–30, 1937.

*THE UNWEATHERED MANGANESE DEPOSITS OF THE BATESVILLE DISTRICT, ARK.**

H. D. MISER AND D. F. HEWETT.

Since its discovery, about 1849, the Batesville district has been the source of a large quantity of manganese oxides that occurred in clays residual from the weathering of the enclosing Fernvale limestone (Ordovician). Since 1928, however, a considerable quantity of manganese carbonate and hausmannite has been mined and shipped from tabular lenses that lie parallel with the bedding and near the top of the enclosing Fernvale limestone and, therefore, close to the overlying Cason shale (Ordovician), which contains nodules (Girvanella) that are rich in manganese carbonate. Although they are largely manganese carbonate, some bodies contain considerable hausmannite, as well as bementite and neotocite. Accessory minerals include hematite, pyrite, barite, and fluorite. The form and distribution of some small bodies of carbonate, as well as the larger bodies, that have been mined indicate that they are related to fractures that cut across the Fernvale limestone but, so far as known, do not extend into the overlying and underlying formations.

It has been known for many years that unweathered Fernvale limestone even remote from bodies of manganese oxide or carbonate contains appreciable manganese carbonate that was probably deposited with the limestone. It seems probable, therefore, that the concentrated bodies of manganese carbonate now being explored were formed by the concentration of the manganese disseminated through the Fernvale limestone, although at present exotic sources cannot be completely dismissed. The widespread presence of bementite, which is only known in deposits of hydrothermal origin, as well as neotocite, barite, and fluorite, indicates that the waters that accomplished this concentration were warm rather than cold. Their source is obscure.

* Indicates that abstract is published by permission of the Director of the Geological Survey, United States Department of the Interior.

EXPERIMENTS BEARING ON THE RELATION OF PYRRHOTITE TO OTHER SULPHIDES.

R. L. HEWITT AND G. M. SCHWARTZ.

The problem of the existence of solid solutions between pyrrhotite and pentlandite, chalcopyrite, galena, and sphalerite was investigated by the heat treatment of suitable ores. Pentlandite was put into solid solution in pyrrhotite above 425° C. and upon slow cooling from 800° C. it unmixed. The unmixed pentlandite oriented itself around pyrrhotite grain boundaries and under high magnifications was observed to contain oriented laths of a mineral tentatively called pyrrhotite. The formation of these laths may be caused by the unmixing of a solid solution of pyrrhotite in pentlandite or by the breakdown of pentlandite expelling pyrrhotite.

Pyrrhotite and chalcopyrite form two solid solutions. Pyrrhotite will dissolve in chalcopyrite above 300° C. The two minerals then react to form chalcopyrrhotite which makes a very fine intergrowth with chalcopyrite in an aureole about pyrrhotite masses in the samples treated. Above 600° C. chalcopyrite will dissolve in pyrrhotite and upon unmixing forms oriented laths in the pyrrhotite.

The eutectic intergrowth formed by pyrrhotite and galena has a composition of approximately 71 per cent galena and 29 per cent pyrrhotite by weight. The eutectic temperature lies between 765° and 775° C. The variation between these figures and those for the artificial PbS–FeS system may be caused by impurities.

Crystallographic intergrowths between pyrrhotite and sphalerite were never produced although such intergrowths have been described and observed in many ores and it is assumed that hydrothermal conditions lower the temperature of formation for such intergrowths considerably below that required in a dry melt.

Small crystals of pyrrhotite, chalcopyrite, and galena were formed and the evidence indicates that they were produced by volatilization and subsequent deposition.

OXIDIZED COPPER ORES OF THE UNITED VERDE EXTENSION MINE.

G. M. SCHWARTZ.

The ores of this deposit show an unusual amount of oxidation and secondary enrichment believed to have taken place during pre-Cambrian time. The ore minerals approximately in order of abundance are: chalcocite, cuprite, malachite, azurite, native copper, chrysocolla, pyrite, chalcopyrite, black oxide, covellite, and bornite. Primary sulphides are pyrite,

chalcopyrite, and presumably bornite. The secondary sulphide ore is almost entirely chalcocite, but a little bornite and covellite are found. Malachite commonly replaced chalcocite directly but also replaced cuprite and occurred as nodular and boulder-like masses as well as in streaks in kaolinite. Azurite formed with malachite apparently in much the same sequence except that it was not found replacing sulphides. Cuprite directly replaces sulphides and is frequently replaced by malachite. Chrysocolla occurs mainly with malachite, and native copper also formed at places during oxidation.

No peculiarities or changes were noted which might be attributed to the pre-Cambrian age of the oxidation. The minerals, their sequence and textural relations seem entirely normal.

*SILICIFICATION TYPES ALONG THE HANGING WALL OF THE LONDON FAULT, MOSQUITO RANGE, COLO.**

ROBERT D. BUTLER (INTRODUCED BY W. H. NEWHOUSE).

Dolomitic formations of Devonian and Mississippian age on the east or hanging-wall side of the London fault, south of Alma, contain replacement orebodies of barite-carbonate-pyrite-sphalerite-galena-tennantite; some contain quartz. The deposits occupy a semicircular area truncated by the London fault. Silicification of the dolomites preceded the formation of the ore minerals. Two types of replacement silica have been observed: (1) idiomorphic, with initial euhedral quartz crystals which became cemented by additional silica into an aggregate resembling a sandy limestone; (2) allotriomorphic, with a felted to a granular aggregate. Serial variations of mineralogic and textural features indicate lateral zoning but the group of deposits as a whole are classed as "cooler" mesothermal. The silicification textures show areal variations in harmony with the zonal concept. Distribution of ore is not related to amount of silicification, but valuable orebodies have been found only within a small area where certain silicified facies are present. The early epigenetic materials, silica, as well as the late, copper, lead, and silver minerals, are really related to the position of the London fault and by their variations indicate the locus of thermal and solution supply.

*RECENTLY ADOPTED AMERICAN STANDARDS FOR CLASSIFICATION OF COAL BY RANK AND BY GRADE.**

THOMAS A. HENDRICKS (INTRODUCED BY T. B. NOLAN).

The purpose of this paper is to call attention to the classification of coals by rank and by grade which have been adopted as American stand-

ards by the American Society for Testing Materials and the American Standards Association. The two standard classifications are summarized, and the hope expressed that economic geologists engaged in coal studies will use these classifications in the future.

ROCK SALT IN PENNSYLVANIA.

R. W. STONE.

Although salt is not now produced in Pennsylvania, a tremendous supply awaits possible future use. Fifteen deep wells in nine counties in the northwestern and western parts of the State encountered beds of rock salt in the Salina formation at depths ranging from 2,300 feet in Erie County to 7,000 feet in Washington County.

Single beds of salt are from 5 to 70 feet thick. One well shows only 15 feet of rock salt, four have more than 100 feet each, and one well record shows 22 beds of rock salt ranging from 6 to 55 feet thick, and with a little shale aggregating 407 feet.

A 10-foot bed of salt would contain about 18,950,000 tons, so one county of 1,000 square miles, like Potter County, would be underlain by an inconceivable quantity.

It is assumed that the deposits are halite, but no samples or analyses are available.

MAGMATIC LEAD ORES.

A REPLY TO PROF. ARTHUR HOLMES.

L. C. GRATON.

Holmes' arresting paper (ECON. GEOL., 32, 763–782) announcing that lead and accompanying metals and gangue-elements of ores cannot have originated from magmas because of isotopic differences between "ore lead" and "rock lead" is analyzed as to conclusion and method. His indicated disparity in atomic weights is found to be doubtful at best and non-conclusive even if established; his reliance on the impossibility of extracting lead with different isotopic proportions from those present in magmas is tested geologically and concluded unsafe; his argument that denies consanguinity of ores and magma is shown to embarrass consanguinity between granites and basalts, and thus to contradict the current ideas of petrogeny as well as to impose otherwise unnecessary and unfounded conditions on the sub-magma region from which he supposes ores to be derived. Some aspects of radioactivity are examined with respect to geological considerations. The various evidences of magmatic origin of ores carefully assembled through the decades are found to survive Holmes' stimulating challenge without casualty.

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THE OUTLOOK FOR ORE DISCOVERIES IN THE LITTLE HATCHET MOUNTAINS, NEW MEXICO.*

SAMUEL G. LASKY.

The Little Hatchet Mountains contain two mining districts, the Eureka silver-lead-zinc district and the Sylvanite gold district, the deposits of each being clustered in and near a monzonite stock. The deposits at Eureka belong to the mesothermal zone whereas those at Sylvanite are hypothermal, but all are mineralogically similar in many respects. The sedimentary formations consist of Lower Cretaceous rocks, which crop out in the two districts, having been duplicated by a large post-ore fault; the stocks and their accompanying mineralized zones lie at essentially the same stratigraphic horizon in the two fault blocks.

The combined evidence of structure, mineralogy, and petrology indicates that the two stocks are actually faulted parts of the same mass and that the Eureka and Sylvanite districts were originally continuous and zonally related, the original stock having been a flat-lying sill-like streamer, 7 miles or more long, that was bordered by a contact metamorphic halo and that formed the core of a zone of ore deposition. The economic implications of this conclusion are three-fold: (1) the ore zone is restricted, like a bedded deposit, to a particular sedimentary horizon; (2) the area between the Eureka and Sylvanite districts, hitherto considered barren, should contain mineralized ground at variable depths below the surface; and (3) the deposits change along the trend of the ore zone from the gold deposits of the one district to the silver-bearing base-metal deposits of the other.

The alternative interpretation is that the Eureka and Sylvanite districts are separate centers of activity, and under that interpretation the outlook for future successful prospecting would depend upon the depths at which the underlying Paleozoic limestones may lie and the possibility of great deposits having been formed in them.

GEOLOGY OF THE CROOKED CREEK DAM SITE, PENNSYLVANIA.[1]

SHAILER S. PHILBRICK (INTRODUCED BY E. B. MATTHEWS).

Crooked Creek dam site, one of the flood control sites for the protection of Pittsburgh, is located in Armstrong County, Pennsylvania, on Crooked Creek, a tributary of the Allegheny River, some 40 miles above Pittsburgh. The proposed dam will be 143 feet high and 1480 feet long, with a single tunnel and uncontrolled spillway. Bed rock at the site is a varied series of

[1] Published by permission of the District Engineer, U. S. Engineer Office, Pittsburgh, Pa.

shales and sandstones with thin beds of limestone, indurated clay and coal belonging to the Allegheny and Conemaugh formations. The abutments are capped by the unconsolidated materials of the Carmichaels formation. Attention is directed to the extensive lensing of the members of the Allegheny formation as indicated by diamond drilling and surface trenching, and as shown in the several geologic sections. The presence of several coal beds in the Kittanning interval is noted and the geologic factors influencing the choice of an earth dam are discussed.

PARAGENETIC COMPARISONS BETWEEN MISSISSIPPI VALLEY LEAD AND ZINC DISTRICTS.

EDSON S. BASTIN.

In spite of the meagreness of the paragenetic data for certain districts a comparison of those data brings out differences as well as similarities between districts. These are discussed and their bearing on genesis considered.

In individual districts repetitions of the full sequence or of any considerable part of it are rare or absent. This fact accords poorly with the meteoric hypothesis, for if the source of the ores is progressive weathering of sedimentary formations, repetitions would be expected.

*NICKEL CONTENT OF AN ALASKAN TROCTOLITE.**

JOHN C. REED.

A troctolite sill about 126 feet thick lies in a thick sequence of greenstone schists, graphitic phyllites, and quartzites on Admiralty Island near Juneau, Alaska. Diorite or gabbro bodies are also present. The sill, called at the outcrop the Mertie Lode, lies near the crest of a large southeastward pitching anticline and is probably only a small part of a much larger body.

The sill is coarse grained with a local diabasic texture. The volumetric proportions of the component minerals of the rock are about 62.3% labradorite, 34.2% olivine, 2.2% pyroxene, 0.82% pyrrhotite, 0.20% magnetite, 0.13% chalcopyrite, and 0.06% pentlandite.

The rock contains about 0.18% chalcopyrite and 0.10% pentlandite by weight. The metal content therefore is about 0.06% Cu and 0.025% Ni (the composition of pentlandite is not definite but the nickel content used in the calculations was 24.65 per cent, which is the nickel content of pentlandite from a not far distant locality on Yakobi Island analyzed by A. H. Phillips).

A chemical analysis by R. C. Wells of a panned concentrate from a chip sample of the sill showed 3½ times as much copper as nickel. This

appears to check within reasonable limits of error of sampling and petrographic measurements, the ratio of copper to nickel of about 2½ to 1 obtained by petrographic measurements.

Assuming that the relative proportions of metallic minerals as determined petrographically is reasonably correct, then a mixture of the opaque minerals of the sill in those proportions, with no silicates, would contain only 1.4% nickel.

*BROADER STRUCTURAL RELATIONS OF THE ORE DEPOSITS OF CENTRAL CITY AND IDAHO SPRINGS, COLORADO.**

T. S. LOVERING AND E. N. GODDARD.

The ore deposits of the Central City and Idaho Springs districts are about thirty miles west of Denver, Colorado, not far from the midpoint of the late Cretaceous-Eocene porphyry belt that extends diagonally across the Front Range from Breckenridge northeast to Boulder. The ore deposits occur in a belt from two to three miles wide trending southwest from Central City for nearly ten miles. The mineralized area is sharply limited at the northeast end by a strong northwest fault whose length exceeds twelve miles. The southwestern end is in line with another persistent northwest fault that begins about two miles southeast of the district. The southeastern edge of the mineralized belt coincides for much of its length with a strong pre-Cambrian shear zone whose length exceeds twenty miles. Near Central City the northwestern limit of mineralization coincides with a contact of pre-Cambrian granite gneiss and schist but a few miles to the southwest where the granite gneiss is absent the limits of the district are less sharply defined. Within the mineralized area most of the ore deposits occur in veins striking from east to northeast but a few important veins strike northwest.

A northeastward trending strip a mile and a half long in the heart of the district is marked by enargite-pyrite-gold-fluorite veins; surrounding this area are the pyrite-gold-chalcopyrite ores from which most of the district production has come, and along the outer limits of mineralization a fringe of silver-bearing galena-sphalerite veins appears. These zonally arranged ores are believed to have been derived from the same igneous source. In a north-south zone about a mile and half long and a half-mile wide in the western part of the district pitchblende ores are found in east-west veins and in a narrow north-northeast zone about a quarter mile wide and five miles long cutting through the eastern part of the district telluride ores occur in east to northeast veins. The telluride zone is directly on the strike of a strong north-northeast fault that first appears near the northern end of the zone but continues three miles be-

yond the district. As the metallizing solutions rose from their igneous source they would naturally tend to spread laterally in cross-fractures and give rise to a progressively broader zone of mineralization with increasing distance from the source. Thus the great length of the telluride zone in comparison with its width suggests that the ores were derived from a nearly linear source not far below the present ore bodies. The much greater width of the pitchblende ore zone suggests that its source was at greater depth, and the extensive area covered by the zonally arranged pyritic gold-silver ores suggests a source at even greater depth. From relations found in the Boulder County telluride districts it is suggested that the telluride ores may be underlain at no great depth by an intrusive latitic explosion breccia that fills a north-northeast fissure and that immediately following its emplacement the breccia may have acted as a hot permeable conduit from a deep lying magma allowing the transport of the telluride-bearing solutions at high temperature to the upper limit of the breccia. A steep precipitation gradient would have existed in the cold rocks above and the tellurides would probably deposit in a relatively thin zone.

A PYROPHYLLITE DEPOSIT IN SOUTHEASTERN NEWFOUNDLAND.[2]

J. S. VHAY (INTRODUCED BY T. B. NOLAN).

Quartz-pyrophyllite schists occur near Manuels, Conception Bay, Newfoundland. The pyrophyllite has been formed by the hydrothermal alteration of sheared and silicified rocks of the pre-Cambrian Harbour Main Volcanics, near a granite contact; the volcanics here consist of rhyolite flows and some clastic material.

The schists consist of various proportions of quartz and pyrophyllite, and grade into large masses of nearly pure pyrophyllite; they exhibit a variety of textures, depending upon the structures of the original rocks. The typical quartz-pyrophyllite schist has quartzose nodules in a matrix of pyrophyllite. Thin sections show coarse pyrophyllite along fractures, and a mat of fine pyrophyllite replacing both the original minerals and the secondary quartz. The flakes of pyrophyllite have a random orientation, and the schistosity is an inherited structure preserved by differential replacement on the planes of schistosity.

Three factors influenced the localization of the pyrophyllite. (*a*) The acidic composition of the host rock. (*b*) The sheared condition of the rock, which itself depended in part upon the original structures of the flows; the schistosity was best developed in the flow-banded, spherulitic, and flow-brecciated types of rhyolite rather than in the massive type.

[2] Published by permission of the Government Geologist, Newfoundland Dept. of Natural Resources.

Because of these factors the schists high in pyrophyllite tend to lie in elongated areas parallel to the strike of the flows. (*c*) Proximity to fissures near the granite contact, which acted as channelways for the hydrothermal solutions.

*THE PROBLEM OF ESTIMATING SAFE YIELD AS ILLUSTRATED BY THE EL PASO, TEXAS, GROUND-WATER INVESTIGATION.**

A. N. SAYRE (INTRODUCED BY O. E. MEINZER).

A recent investigation of the ground-water supplies of the El Paso, Texas, area made by Penn Livingston and myself affords an example of some of the problems encountered in estimating the safe yield of water-bearing formations. The cities of El Paso and Juarez and the local industries draw water from more or less unconsolidated sands and gravels interbedded with clays, which fill the deep structural basin between the Franklin and Hueco Mountains.

Most of the wells are 600 to 800 feet deep. Beneath the intermontane upland or mesa the water occurs under essentially water-table conditions, and none of the water-bearing beds near the pumped areas yield highly mineralized water. Beneath the Rio Grande Valley, which is incised 200 to 350 feet beneath the surface of the basin, supplies of fresh water are obtained from beds that lie between horizons of mineralized water.

The average daily pumpage for the whole area has increased from about a half-million gallons in 1906 to 15.4 million gallons in 1935. About 90,000 acre-feet has been pumped from the mesa wells and about 210,000 acre-feet from the valley wells. The volume of the cone of depression formed by pumpage on the mesa is about 126,000 acre-feet and the specific yield about 17.5 per cent. Thus in this area about 22,000 acre-feet, or one-fourth of the pumpage, was taken from storage and about three-fourths was taken from recharge. In the valley the cone of depression is larger, but only partly outlined, because of the lack of information in Mexico. However, it is believed that in the valley also large quantities of water have been furnished from recharge.

Recharge to the water-bearing formations occurs along the eastern slopes of the Franklin and Organ Mountains, along the north slope of Sierra del Paso del Norte and perhaps from the Rio Grande.

FLUORITE DEPOSITS IN WESTMORELAND, N. H.

H. M. BANNERMAN AND R. E. STOIBER.

The fluorite deposits in Westmoreland, New Hampshire, occur as fissure fillings in a series of tension fractures in granite gneiss. The veins

being worked are from three to five feet in width, and some of them have been traced laterally five to six hundred feet. They dip approximately 70 degrees while the foliation of the gneiss in which they lie is generally quite flat. The veins are banded, crustified, and replete with open cavities. The fluorite is accompanied mainly by quartz, but considerable quantities of barite, calcite, dolomite, kaolin and sericite are present, and streaks of such sulphides as chalcopyrite, pyrite, sphalerite and a little galena appear throughout the deposits, together with some finely crystallized malachite and smithsonite. The veins have suffered no appreciable deformation since their deposition. Data at hand suggest that they are of post-Palaeozoic age—possibly Triassic.

*GEOLOGY OF THE SAVAGE RIVER, MD. DAM SITE.**

EDWIN B. ECKEL.

A geologic investigation of the Savage River dam site, in western Maryland, recently made by the Geological Survey at the request of the Army Engineers, followed ideal lines in that the geologist had an active part throughout the program of exploration and design.

The proposed dam will rest on a series of well-consolidated beds of sandstone, sandy shale, and limestone of Paleozoic age. The beds are unfaulted and dip downstream at low angles. Sound bedrock occurs close to the level of the present stream across the entire width of the valley floor. Deposits of earth suitable for construction of the dam are scattered and thin but are adequate for the purpose.

Knowledge of the geology of the site was particularly useful in discussions bearing on the engineers' choice of limestone rather than sandstone for the abutments, the desirability of using shale in the permeable part of the dam, and on the thickness of the weathered zone. Physiographic studies led to the belief, which was later proved, that no buried channels exist beneath the present valley floor.

MAGMATIC CARBONATION—CARBOTHERMAL METAMORPHISM.

R. J. HOLDEN.

The action of carbon dioxide at shallow depth in changing high silicates to lower hydrous silicates and carbonates of the bases and setting free colloidal silica has long been recognized. Carbonate association with secondary silicates at shallow depth is evidence of the agency of carbon dioxide—magnesite with serpentine and talc, other carbonates with other secondary silicates. The agency of both meteoric and magmatic waters

is generally recognized. It now seems that we may recognize the results of mass action of magmatic carbon dioxide by the association of carbonates with chlorite, epidote and other secondary hydrous silicates in deep veins and near intrusives in katamorphic changes at depths and temperatures where only anamorphic actions would be expected. Magmatic carbon dioxide, in some cases with the aid of sulphur, may produce sericitization, propylitization, alunitization, silicification and pyritization. The term carbothermal instead of hydrothermal indicates the active agent.

*THE NATURE AND SIGNIFICANCE OF THE CONE OF DEPRESSION IN GROUND-WATER BODIES.**

C. V. THEIS (INTRODUCED BY O. E. MEINZER).

Whether a ground-water supply from wells represents water diverted from natural outlets of the ground-water system or water taken from storage in the aquifer depends primarily on the areal relation between the natural outlets and the cone of depression caused by the discharge of the wells. No mathematical expression considering all the factors governing the nature of this cone appears to be available, but such an expression is available for the cone in an ideal homogeneous aquifer of constant transmissibility. Using this as a criterion, the future lowering of water levels throughout natural aquifers from which ground water is taken can be considered in some detail. The ultimate limits of the cone are the boundaries of the aquifer. Until water can be diverted in significant amounts from natural outlets of the aquifer, the cone broadens and deepens at a constantly decreasing rate under uniform conditions of discharge by wells. The speed of development depends largely on the amount of water taken from storage in the aquifer either by drainage, if the aquifer is non-artesian, or by compression of the aquifer if it is artesian. The apparent magnitudes of the quantities involved in the two types of aquifers indicate that usually the cone should develop in artesian aquifers much more rapidly than in non-artesian—probably 10 to 1,000 times as fast. Hence, in regard to time taken to divert water from natural outlets of the aquifer, large artesian aquifers are likely to be comparable to much smaller non-artesian aquifers. Eventually in any aquifer, if discharge by wells continues, and especially if the locality of development is so located with respect to points of natural discharge or recharge that the cone of depression effectively includes these points after a short period of development, the hydrologic conditions in the recharge and discharge areas become the limiting factors in the development. For many present ground-water developments, however, the time when these factors become of great importance appears to be in the rather distant future.

*PLATINUM PLACERS OF THE GOODNEWS BAY DISTRICT, ALASKA.**

J. B. MERTIE, JR.

Goodnews Bay is a shallow inlet of Bering Sea that indents the southwest coast of Alaska, about 100 miles south of the mouth of the Kuskokwim River. The Goodnews Bay Mining District lies north and south of this inlet, but placer platinum has been found only in a small area south of Goodnews Bay. These deposits were discovered 11 years ago, and for the last three years have been worked by drag-line excavators. The production for 1937 will be about 5,500 ounces, but an 8-foot dredge is now under construction, so that the production for 1938 doubtless will be much greater.

The country rock consists of sheared and semi-schistose fragmental rocks, of sedimentary and igneous origin, and lava flows, all of which are probably of Carboniferous age. The sedimentary rocks include chert, quartzite, graywacke, argillite and slate; and the igneous rocks comprise lavas and tuffs, mainly of basaltic character. These rocks are intruded by two bodies of ultrabasic rock, which (without petrographic examination) are designated as dunite. One of these masses forms an elongate ridge, about 7 miles long and 2 miles wide, called Red Mountain, which is the bedrock source of the platinum placers that are now being worked. One large intrusive mass of granitic rocks also occurs in this district, and small dikes of such material cut the dunite. About 100 miles to the northeast is a rugged mountainous region, which was the site of severe glaciation during the Pleistocene, during which period large glaciers reached westward and southward to Bering Sea. The area in which the platinum placers are found, however, was not in the path of these radiating ice-tongues, and was therefore not glaciated.

The principal platinum placers occur in the valley of Salmon River, and in two of its tributaries, known as Platinum and Clara Creeks, which drain the eastern and southern slopes of Red Mountain. The alluvium of Platinum and Clara Creeks ranges in thickness from 12 to 20 feet, but is considerably thicker in the main valley of Salmon River. Most of the platinum occurs on, and in the crevices of bedrock, but some is also found in the gravels for 2 to 3 feet above bedrock. All six of the platinum metals are present, but platinum constitutes from 68 to 75 per cent of the product, and iridium from 6 to 13 per cent. The content of palladium is very low, ranging from a quarter to a half of one per cent. A small amount of free gold, ranging from a half of one per cent to one and a quarter per cent, is also recovered. The concentrates taken with the precious metals include principally magnetite, ilmenite and chromite, of which chromite is known to be intimately associated with the platinum metals.

GOLD DEPOSITS OF NORTHERN ORIENTE, CUBA

TERENCE T. QUIRKE (INTRODUCED BY M. M. LEIGHTON).

(To be read by title.)

There are two main gold mining districts in Oriente province, one at Holguin, and the other northeast of Santa Lucia mills. That near Holguin has depended largely upon gold-bearing arsenopyrite, from the weathered outcrops of which exceedingly rich pockets have been worked out by the aborigines and by the early Spanish colonists. The deposits occur in irregular veins and disseminations closely related in distribution to surfaces of igneous contact and cross fracturing.

Near Santa Lucia the gold occurs in rough coarse and fine grains within massive serpentine rocks, in quartz veins, in arsenopyrite concentrations of massive forms, and in shatter zones with no visible quartz or other vein minerals. The distribution in bed rock is irregular, but nearly all the local gravels and other alluvium contain free gold.

SCIENTIFIC NOTES AND NEWS

CHESTER W. WASHBURNE has returned from field work in Venezuela. He has moved his office from 149 Broadway to 50 Church St., New York City, where he will handle also the consulting work of Frederick G. Clapp during his absence in the Near East.

FREDERICK G. CLAPP has left Iran to spend some time with the geologists of the Inland Exploration Co. now in the field in Afghanistan.

E. S. MOORE has been appointed head of the department of geology at the University of Toronto.

D. M. DAVIDSON of Minneapolis and Northern Rhodesia was married on October 28 to Bernadine Dunn of Minneapolis.

JOSEPH A. TAFF has retired from active service as consulting geologist of the Tide Water Associated Oil Company, San Francisco. His career began with the Arkansas Geological Survey in 1888, and continued with the Texas Geological Survey, 1889–1894, and with the U. S. Geological Survey, 1894–1901. He was chief geologist and consulting geologist for the Southern Pacific Co. and affiliated oil companies, 1909–1932, and consulting geologist to the Associated Oil Co., 1932–1937. Mr. Taff's home address is 628 Cowper St., Palo Alto, California.

DOUGLAS JOHNSON has been appointed executive officer of the department of geology and mineralogy at Columbia University, New York.

FRANK T. M. WHITE, formerly of Mount Magnet, Western Australia, is now mining engineer to the Department of Mines in the Colony of Fiji.

GEORGE S. RICE, chief mining engineer of the U. S. Bureau of Mines, has retired from the Bureau.

JOHN W. GRUNER is in Germany for the John A. Savage Co., consultants to the Reichswerke "Hermann Göring," helping locate and mine iron ore for the "Four Year Plan."

THE A. A. P. G. at their October Pittsburgh meeting ended with $135 excess excursion money because so many attended! Remarkable! It is now a fellowship fund available for any recommended graduate student in geology with a problem to study. Apply to M. G. Gulley, Box 1166, Pittsburgh, Pa.

THE SOCIETY OF ECONOMIC GEOLOGISTS program for the Christmas meetings is as follows: (For titles of papers see preceding abstracts).

Tues. A.M., Dec. 28: G. S. A. session, and papers by E. S. Bastin and L. C. Graton; Luncheon at 12:00.

Tues. P.M., Dec. 28: Joint session with G. S. A. and M. S. A. Papers by E. P. Kaiser,[1] A. L. Howland,[1] L. W. Currier,[2] C. A. Anderson,[2] P. F. Kerr,[1] H. D. Miser and D. F. Hewett, J. S. Vhay, J. C. Reed, E. N. Cameron,[1] R. D. Butler, R. L. Hewett and G. M. Schwarts, H. M. Bannerman and R. E. Stoiber. ([1] refers to M. S. A. papers; [2] to G. S. A. papers.)

Wed. P.M., Dec. 29: Papers by R. J. Holden, T. A. Hendricks, G. M. Schwartz, R. W. Stone, S. G. Lasky, J. B. Mertie, Jr., T. S. Lovering and E. N. Goddard, C. V. Theis, A. N. Sayre, E. B. Eckel, S. S. Philbrick, T. T. Quirke. Annual business meeting.

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